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**Economic Evaluation of the Major Hydrocarbon
Producing Regions in Texas**

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**Economic Evaluation of the Major Hydrocarbon
Producing Regions in Texas**

by

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Dedication

To my parents, Galina and Ricky, for teaching me the value of support and perseverance.

To my partner, Lindsay, for providing unconditional love and encouragement.

To my sister, Dariya, for showing me the value of friendship and kindness.

*To Philippe E. Tissot, for equipping me with the skills and knowledge
that were required to complete this work.*

Thank you.

Abstract

Economic Evaluation of the Major Hydrocarbon Producing Regions in Texas

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Technological advances in hydraulic fracturing and microseismic analysis coupled with horizontal wellbore drilling have allowed access to low-permeability sedimentary formations that were previously considered uneconomical to exploit. The rapid growth in domestic oil and gas extraction directly affects local communities, namely those that overlay the lucrative hydrocarbon formations. This thesis provides a holistic, regional scale analysis of the economic expansion bolstered by the recent advances made in unconventional exploration. In particular, the work focuses on Texas where upstream development has been pronounced over the past decade. First, a spatial distribution analysis was conducted in order to capture the shifts in hydrocarbon exploration throughout the state. Subsequently, the research evaluated variations in economic growth between counties that were actively engaged in the recent drilling boom and those that were not. Based on a fixed-effects regression model, I estimated that the recent boom has had a significant positive impact on local employment. Despite the positive effect on jobs, the model suggests that the influence on average wages was minimal. Additionally, economic

trends of coastal counties with extensive downstream development were analyzed. This analysis highlighted a direct impact on maritime shipping trends. In order to predict potential future trends, a financial valuation study was conducted by approximating the break-even prices of different formations and comparing them to projected commodity price scenarios. Lastly, a discussion was formulated about potential policy implications and how policy can retain, stabilize, or hinder growth in hydrocarbon producing regions.

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Acronyms and Abbreviations Used in this Thesis

ASFMRA	American Society of Farm Managers and Rural Appraisers
bbl	Blue barrel (oil barrel unit)
BCFD	Billion cubic feet per day
BCFG	Billion cubic feet of gas
CBP	County Business Patterns
DCF	Discounted Cash Flow
DOE	U.S. Department of Energy
E&P	Exploration and production
EIA	Energy Information Administration
EUR	Estimated ultimate recovery
FERC	Federal Energy Regulatory Commission
GIS	Geographic Information System
IRR	Internal Rate of Return
LNG	Liquefied natural gas
LTO	Light tight oil
MA	Mega-annus (unit of time equal to 1 million years)
Mbbl	Thousand barrels
MCF	Thousand cubic feet
MMBNGL	Million barrels of natural gas liquids
MMBO	Million barrels of oil
MMCF	Million cubic feet of gas
MSA	Metropolitan Statistical Area
NAICS	North American Industry Classification System
NGL	Natural gas liquids
NPV	Net present value
OPEC	Organization of the Petroleum Exporting Countries
QCEW	Quarterly Census of Employment and Wages
R _o	Vitrinite reflectance
RRC	Railroad Commission of Texas
RUCC	Rural-Urban Continuum Codes
TCFG	Trillion cubic feet of gas
TCPA	Texas Comptroller of Public Accounts
TOC	Total organic carbon
TWC	Texas Workforce Commission
TxDOT	Texas Department of Transportation
USDA	U.S. Department of Agriculture
USDOT	U.S. Department of Transportation
USGS	U.S. Geological Survey
WCUS	Waterborne Commerce of the U.S.
WTI	West Texas Intermediate

Chapter 1. Introduction

Recent technological advances in hydraulic fracturing and microseismic analysis coupled with horizontal wellbore drilling have allowed access to high-organic, impermeable sedimentary rock formations that were previously considered uneconomical to exploit. Consequently, domestic U.S. oil and natural gas production has surged to unprecedented levels, even outpacing major hydrocarbon producers like Saudi Arabia and Russia (EIA, 2013). This rapid growth in oil and gas extraction can directly benefit local communities, namely those that overlay the lucrative hydrocarbon formations. As a result, continued industry investments in these regions have transformed local employment and public revenue trends (Tunstall et al., 2014). Moreover, the recent resource boom indirectly affected the broader U.S. economy. The sudden oversupply of natural gas has lowered its U.S. market price, making the commodity more attractive to domestic manufacturing and petrochemical sectors, which utilize natural gas as a feedstock (DOW, 2012). Particularly, natural gas-intensive industries like fertilizer and polyethylene manufacturers witnessed rapid growth during the period of low natural gas prices (Hausman and Kellogg, 2015). The downward pressure on domestic natural gas prices is anticipated to be sustained for years to come (Kersley et al., 2012). In addition to local and national developments, rapidly rising supplies of U.S. oil and gas have impacted the global commodity trade. For example, between 2007 and 2014, U.S. oil and natural gas imports decreased by 32 percent and 42 percent while exports rose by 192 percent and 82 percent respectively (Figure 1.1).

All of these fast paced developments are dynamic and pose significant implications for the future of domestic U.S. energy and related economic sectors. The benefits and drawbacks associated with regional production are closely tied to the global economy and a volatile global oil market. When supply exceeds demand for prolonged periods, prices

may pullback or even collapse as was observed in 1986, when OPEC increased their share of the oil market while global oil demand was essentially plateauing (Gately et al., 1986). Similarly, the 1998 Asian Economic Crisis generated an oil price crash that exogenously prompted a sharp reduction in U.S. drilling activity (Kellogg, 2014). The most recent precipitous decline in oil prices started in August 2014. This decline emphasizes that unless there is sustained growth in global demand, or coordinated curtailment of supply, marginal producers that are engaged in capital intensive unconventional drilling run the risk of being forced out of the market. Thus, careful evaluation of recent industry trends is essential in order to estimate potential future effects of rapid changes in drilling on global economies. Furthermore, it is crucial to analyze how production impacts regional communities, specifically focusing on the effects associated with shifting commodity prices.

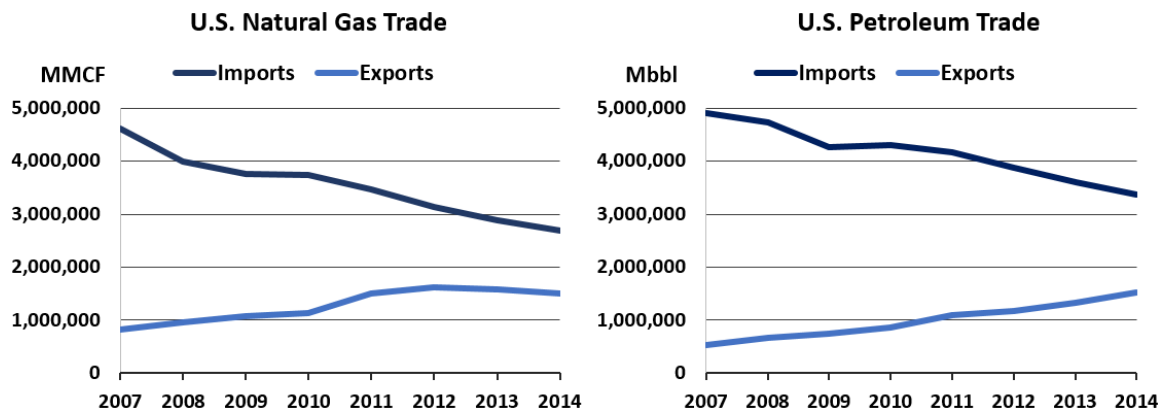


Figure 1.1: Recent trends in U.S. natural gas and petroleum trade. Since 2007, the U.S. trade deficit for oil and natural gas has been declining. Graphs were compiled based on data from the Energy Information Administration (EIA).

The objective of this thesis is to provide a holistic, regional scale analysis of the economic expansion bolstered by the recent advances made in unconventional exploration. In particular, this thesis focuses on Texas where upstream development has been pronounced over the past decade. First, a spatial distribution analysis was conducted in

order to capture any shifts in hydrocarbon exploration throughout the state. Based on this analysis, an examination was made of the shift in production from dry gas-bearing formations to oil and natural gas liquids (NGL) - bearing formations in response to decreasing natural gas prices. Subsequently, the research captured variations in economic growth between rural and urban counties as well as counties that were actively engaged in the recent drilling boom and those that were not. In order to accomplish this, the counties were subdivided into the following categories: metropolitan, urban, and rural in decreasing order of population. Likewise, the counties were classified by the amount of drilling activity that has occurred within each one. Economic trends of coastal counties with extensive downstream footprints (refining facilities and shipping ports) were also analyzed. In order to predict potential future trends, a valuation study was conducted by approximating the break-even prices of different formations and comparing them to projected commodity price scenarios. Lastly, a discussion was formulated about potential policy implications and how policy can retain, stabilize, or hinder growth in hydrocarbon producing regions. The remaining chapters are organized as follows:

- Chapter 2 - background and literature review
- Chapter 3 - data acquisition and quality control
- Chapter 4 - regional exploration and production shifts
- Chapter 5 - economic and statistical analysis of the affected counties
- Chapter 6 - assessment of the coastal (downstream) counties
- Chapter 7 - evaluation of the five hydrocarbon plays and financial sensitivity analysis
- Chapter 8 - discussion and policy implications
- Chapter 9 - conclusions

Chapter 2. Background

Shale is a common fine-grained ($< 1/256$ mm), sedimentary source rock that often serves as a caprock, forcing hydrocarbons to accumulate within conventional geologic reservoirs (USGS, 2013). When extremely low permeability rocks like shale are saturated with hydrocarbons a caprock is not required and the rock is deemed an unconventional reservoir. As Roen (1984) notes, shale formations that consist of high organic matter, have long attracted attention as a viable source of energy. Unlike the economic risks associated with conventional reservoirs, risks related to unconventional exploration mostly revolve around obtaining sufficient production rates, rather than finding hydrocarbon accumulations (Schmoker et al., 1996). Withdrawal of hydrocarbons from these unconventional formations has been considered uneconomical, until the early part of the 2000s when emergent drilling and completion methods began to take root. Generally, modern extraction of oil and gas from unconventional formations requires the complementary techniques of horizontal drilling and hydraulic fracturing, making the overall process capital intensive (Kaiser, 2012a).

The ‘shale revolution’ began in North Texas where the combination of high natural gas prices and innovative drilling techniques spurred efforts to fracture organic-rich shale facies horizontally (Yergin, 2011). Today, Texas is home to four major unconventional oil and gas plays; the Barnett Shale in North Texas, the Eagle Ford Shale in South Texas, the Haynesville-Bossier Shale in East Texas, and the Granite Wash Sandstone in the Texas Panhandle (Figure 2.1)¹. In addition to extensive unconventional plays, West Texas overlays the Permian Basin, which encompasses some of the largest conventional oil

¹ Note: smaller productive formations like the Woodbine, the Wolfcamp, and the Cline shales are collocated with the five primary hydrocarbon regions (e.g. Eagle Ford completion analysis merges data from the Woodbine Shale).

producing reservoirs in the contiguous United States (Tennyson et al., 2012) as well as multiple unconventional plays. Combined, the aforementioned sedimentary formations span across approximately 130 of the state's 254 counties.

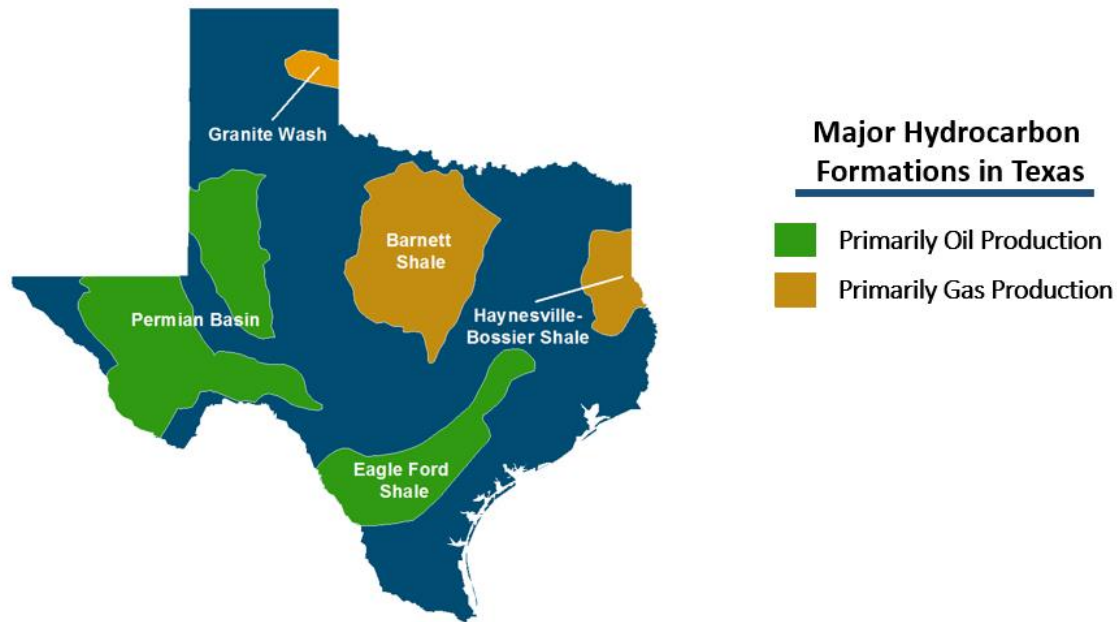


Figure 2.1: Major conventional and unconventional oil & gas production areas in Texas.²

As evident from Figure 2.1, the hydrocarbon formations are dispersed throughout the state. They also vary in organic content, geologic characteristics, and economic potential. The extensive regional coverage and contrasting geologic characteristics of the reservoirs make Texas an ideal study area for analyzing the economic impacts of oil and gas production. Another critical component that makes the state a unique case study is its downstream refining and maritime shipping capacity stretched along the Gulf of Mexico. In 2014, Texas operated four of the ten largest U.S. refineries ranked by capacity (EIA, 2014a) and three of the ten largest ports ranked by tonnage (USDOT, 2014). These

² The compiled map is based on state outline data from ESRI and basin/shale shapefiles from the EIA. The outline of the Granite Wash sandstone is *estimated* due to a lack of available geospatial data.

industrial complexes can supplement economic growth in counties that lie outside of the production reservoir boundaries. Essentially, the sheer scale and diversity of the oil and gas industry in Texas allows for a comprehensive impact assessment of the recent natural resource boom.

Literature Review

Previous studies have analyzed the regional impacts of natural resource booms. Jacobsen and Parker (2014) analyzed the 1970s-1980s oil boom-bust cycle that occurred throughout the western U.S. The authors found that there was a substantial positive impact on income and employment during the boom, with an economic contraction following the boom. The study estimated that economic conditions were worse post-boom than they would have been in the absence of a boom. However, the authors also note that under reasonable discount assumptions, the estimated Net Present Value (NPV) of the economic measures over the whole study period was positive.

Maniloff and Mastromonaco (2014) conducted a study to evaluate national trends from 2000 to 2010. Analogous to the Jacobsen and Parker study, Maniloff and Mastromonaco found a positive relationship between new gas development and employment/income. They estimated that approximately three percent growth in county employment was associated with every doubling of drilled wells. Furthermore, the authors found that the majority of the job growth was contained in the mining (oil and gas) sector, with some increases in the construction sector. Finally, the authors highlighted that continued innovative advances in hydraulic fracturing processes lower the cost of production, thus potentially reducing some of the negative impacts that are associated with a price-driven bust.

Hausman and Kellog (2015) provided broad-scale national estimates of the impact on both consumers and producers from the shale gas boom. Their study estimated that the reduction in natural gas prices (in response to resource oversupply) increased the consumer welfare by approximately 74 billion dollars per year from 2007 to 2013. Meanwhile, the producers lost 30 billion dollars per year. Overall, the authors estimated that the national welfare increased by 48 billion dollars per year, excluding any environmental damage costs. Additionally, the authors found that among the major natural gas consumer sectors, electric power and industrial sectors witnessed the largest surplus gains.

Another national level study focused on comparing *direct* economic impacts to *spillover* effects of the recent drilling boom. Feyrer et al. (2015) estimated that the economic impact of regional oil and gas production extends to the surrounding counties outside of the core production areas. The authors attributed an increase of approximately \$227,000 in regional wages and \$126,000 in royalties for every million dollars in production revenues. Furthermore, their analysis estimated that the recent production boom lead to a total increase of 650,000 jobs in the U.S. during the 2008 financial crisis.

Additional studies have observed how the recent shale boom affects individual variables like rural land value and housing prices. A 2012 report on rural land value trends in Texas described how the volume of land sales in the Eagle Ford Shale region of South Texas was increasing, but had not reached pre-2008 recession levels. The authors also noted that demand for recreational ranches was higher outside of the hydrocarbon producing region. In the core area, ranches with mineral rights were in demand, while ranches with mineral rights severed from the surface rights were met with market resistance (ASFMRA, 2013).

Muehlenbachs et al. (2014) looked at the impact of shale development on property values in the Marcellus Shale region of Pennsylvania. Their study describes a negative

relationship between groundwater-dependent homes in the production areas and their respective property values. This suggests that the negative perception of potential groundwater contamination still exists among the general public in this region. Interestingly, the research also determined that home values increase if the properties rely on piped water and are collocated with production wells, highlighting the positive effect of mineral royalty payments on housing prices.

Similar to the first three studies, the analysis presented in this thesis measured county level economic variables such as employment and income. In contrast to the previously mentioned papers, this thesis focused on regional dynamics between different hydrocarbon plays in Texas. In particular, this thesis analyzed how globally and nationally-driven commodity prices impact the local production regions. It is important to remember that lower economic growth translates into lower energy demand, making these factors intertwined. Ultimately, any energy resource development is sensitive to its respective market price. Thus, breakeven prices are estimated in order to define a benchmark at which marginal producers become discouraged from continuing to drill.

Chapter 3. Project Data Acquisition

Completion and Production Data

A comprehensive study of drilling and production activities throughout Texas requires substantial amounts of industry data. DrillingInfo, a proprietary database was utilized to extract individual well completion and production information. Since the first commercially successful unconventional well completions were achieved in the early 2000s, the 2000-2013 timeframe was selected for the study period. Completion data was acquired to capture parameters associated with the preparation of a well for production, which often follows drilling activities. Production data, on the other hand, provided an assessment of how the wells behaved once production was initiated.

In order to evaluate the annual regional distribution of oil and gas development, well completion data was applied, including, *well location*, *well type*, *drill type*, *total well depth*, and *completion date*. Each variable served a distinct purpose. For example, *well type* was coupled with *well location* to illustrate the geographic shifts between oil-producing areas and gas-producing areas. Considering that conventional wells are typically drilled vertically while unconventional wells are associated with horizontal drilling, *drill type* was combined with *well location* to indicate the overall shift from conventional exploration to unconventional exploration. The *total well depth* variable allowed for evaluating costs associated with drilling longer horizontal wellbore laterals. Lastly, the *completion date* was applied to all measures as the time variable.

While the primary purpose of completion data was to capture general regional distribution trends, production data was utilized to calculate the average estimated ultimate recovery (EUR) volumes for each of the five hydrocarbon plays. This information is crucial for conducting financial sensitivity analysis. As a way to calculate the EUR values, a common technique known as decline curve analysis must be performed. This technique

requires the following parameters: *initial production rate*, *initial decline rate*, and *the degree of curvature (b-factor)*. The former two variables were provided by DrillingInfo while the *b-factor* was estimated by fitting the predicted curves to historic data.

Once all the data was retrieved and organized by year, a number of quality control measures were taken in order to remove bias and errors from the datasets. Misspellings and missing well-reservoir associations are common problems that occur when downloading data by reservoir name. Thus, instead of downloading the data by reservoir name, all the available Texas well data was referenced to geographic coordinates and plotted in a GIS. Data elements with missing, inaccurate, or offshore (e.g. Gulf of Mexico wells) coordinates were discarded. Once the wells were plotted, a geographic boundary dataset for each formation was overlaid to subdivide the completion and production values by their respective hydrocarbon play areas. Another issue that occurred within the dataset was that some of the downloaded oil and gas wells were categorized as either *injection*, *disposal*, *water*, *dry hole*, or *unknown*. These entries were discarded in order to avoid a miscounting of production wells. The final quality check involved removing extremely high or low transcription error values that could bias the calculations. Table 3.1 provides a summary of the completion and production datasets after the described quality control measures were applied.

Completion Dataset	Percent Complete	Production Dataset	Percent Complete
Total Well Depth	98%	Initial Production Rate	98%
Drilling Commenced	96%	Initial Decline Rate	95%
Drilling Completed	96%		
Reservoir Name	84%		
Date of First Production	89%		

Table 3.1: Completeness summary of production data as a percent of the raw dataset.

Employment, Wages, Hotel, Road Maintenance, and Traffic Accident Data

Numerous variables are required to measure and compare the economic impact between counties. Quarterly Census of Employment and Wages (QCEW) data was obtained from the Texas Workforce Commission (TWC) for all the statewide counties, covering the entire study period. Considering that many economic variables may be affected by local energy production, additional focus was placed on individual industries, including mining, construction, financial activities, professional and business services, and transportation/utility sectors. In order to accomplish this, the QCEW data was subdivided by individual North American Industry Classification System (NAICS) codes. Most of the datasets were complete, although some rural counties excluded industry level data because a low number of institutions filed annual reports³. Exclusion of this data is most evident for counties in the rural Permian Basin and Granite Wash regions. For counties whose wage and employment data included considerable gaps, all the remaining values were removed to provide a consistent economic growth comparison. Table 3.2 provides a completeness summary of the final dataset after the application of quality control. The counties were also cross-referenced by their respective Rural-Urban Continuum Codes (RUCC). The 2013 RUCC data was acquired from the USDA.

Employment Datasets	Percent Complete		Wages Datasets	Percent Complete	
	Producers	Non-Producers		Producers	Non-Producers
Total Employment	100%	100%	Total Wages	100%	100%
Mining Activities	98%	97%	Mining Activities	98%	97%
Construction Services	96%	98%	Construction Services	96%	98%
Financial Activities	93%	91%	Financial Activities	93%	93%
Professional & Business	91%	93%	Professional & Business	92%	93%
Trade, Transport & Utilities	99%	99%	Trade, Transport & Utilities	99%	99%

Table 3.2: Completeness summary of employment and wage data among counties as a percent of the raw dataset.

³ Withholding of this data is intended to protect the confidentiality of the reporting institutions.

In addition to expanding local employment, natural resource booms often attract migratory labor (Jacobsen and Parker, 2014) which can lead to increased demand in hospitality services. Thus, an analysis of the hospitality industry trends was also conducted for each study region to proxy for the impact of migratory labor. Annual hotel revenue and nights-sold information was acquired from the Texas Hotel and Motel Annual Reports, provided by the Texas Office of the Governor. Similar to the QCEW data, many of the rural counties had missing data. Otherwise, the datasets provided a useful gauge of regional hospitality-related patterns. Overall, 88 percent of the oil and gas producing and 85 percent of the non-producing county hospitality datasets were complete.

In order to evaluate financial growth among the counties, annual gross sales information was acquired from the Texas Comptroller of Public Accounts (TCPA). The dataset was further subdivided into three categories including, mining, wholesale, and retail trade. This was intended to provide more detail on the mining-related trends and growth patterns among the primary sales sectors. Additionally, countywide annual lateral road expenditures data was acquired from the TCPA and annual traffic accident data was acquired from the Texas Department of Transportation (TxDOT). These two datasets were applied in the analysis as a means to capture some potential negative impacts of rapid oil and gas development.

Supplemental Downstream Sector Data

In order to measure trends in the downstream sectors, maritime commerce and refining data was collected for coastal counties in Texas with extensive petroleum refining or shipping capacity. The waterborne petroleum volumes were obtained from the annual Waterborne Commerce of the U.S. (WCUS) reports provided by the U.S. Army Corps of Engineers. The WCUS data was subdivided by major Texas ports and various shipping

categories. Meanwhile, the operable refining capacity and utilization rate data was obtained from the EIA. Finally, employment and wages data for petroleum refineries and port/harbor operations was obtained from the TWC to provide an estimate of annual employment patterns in the downstream sectors. It should be noted that because of confidentiality guidelines, the employment and wages data could not be released on the county level. Thus, the data was analyzed by the respective Metropolitan Statistical Areas (MSAs).

Through compilation and analysis of the described datasets, the subsequent chapters provide an in-depth overview of the production and economic trends in each of the five major hydrocarbon production regions.

Chapter 4. Regional Dynamics of Oil and Gas Exploration in Texas

Exploration and production of oil and gas has long been embedded in the history of Texas. The first production well was drilled in Nacogdoches County in 1866. Three decades later, the state witnessed a transformational event with the completion of its first major gusher at the Spindletop oil field in January of 1901 (RRC, 2014). Creation of oil and natural gas requires a strict combination of conditions, including the settling of organic matter in low oxygen environments, undergoing burial, and exposure to substantial pressure and heat during an extensive geologic period. Throughout its geologic history, Texas has undergone repeated inundations by shallow seas, leading to accumulations and eventual burial of sediments (Bartberger, et al., 2003; Dyman and Condon, 2006). In the modern day, the state is home to numerous sedimentary formations that are exploited for oil and gas.

Regional activity shifts between the five reservoirs that are the focus of this thesis, are driven by factors like geological formation characteristics, new technological developments, and commodity prices. While geologic uncertainty and technologic risk play an important role, commodity prices are the ultimate determinant of the natural resource potential (Kaiser, 2012b). Accordingly, oil and gas operators estimate their proved reserves based on the respective commodity price projections (EIA, 2014b). It is however, important to note that price-driven oil and gas operations are more complex than the basic fluctuation of petroleum prices. For instance, operators with lower costs (such as those drilling in formations that are near distribution networks) may withstand lower prices than those with higher costs. Furthermore, NGLs such as ethane, propane, and butane are often collocated with ‘dry’ gas (methane). These ‘wet’ gases are priced separately from dry gas and are typically influenced by crude oil prices. Thus, operators may shift to NGL-rich

areas of the shale play when prices for these associated resources are high. This results in extended production during periods of low natural gas prices (EIA, 2014c). Other major factors that may extend production include futures and lease-hold contracts. As Kaiser (2012b) notes, some operators may be obligated to drill, regardless of the commodity price due to previous contract agreements.

Additionally, as emphasized by Anderson, Kellogg, and Salant (2014), it is important that a distinction is made between development and production. Oil and gas *production* from an existing well is not necessarily dictated by the respective commodity price. Instead, once a well is in production, production levels are constrained by the natural geologic reservoir pressure. Whereas, in regards to *development* of new wells, price strongly influences future drilling activity as operators respond to price fluctuations. Typically, operators utilize price estimates in order to determine whether or not to commence drilling. Subsequently, once the well is drilled and completed, the price has negligible impact on the rate of production (Anderson, et al., 2014; Kellogg, 2014). These dynamics are further highlighted by Fitzgerald (2013), who demonstrated that the number of drilling rigs is sensitive to the expected commodity price. For this reason, the regional oil and gas development shifts described in the following section are closely evaluated with respect to shifts in price.

Statewide Regional Shifts in Reservoir Development

Throughout the study period, Texas has undergone significant regional shifts between primary production areas. Initial unconventional gas production was concentrated in the Barnett Shale core area with limited expansion occurring in the Haynesville Shale region in 2008 (Figure 4.1a). This expansion was triggered by increasing natural gas prices and technological breakthroughs in horizontal drilling combined with slick-water

fracturing techniques (Bruner and Smosna, 2011). The increasing trend in unconventional gas completions sharply reversed after the price of natural gas collapsed in 2009. Following the price collapse, horizontal completions rapidly declined in the Barnett area as operators shifted to more lucrative NGL and oil windows of the Eagle Ford Shale (Figure 4.1b).

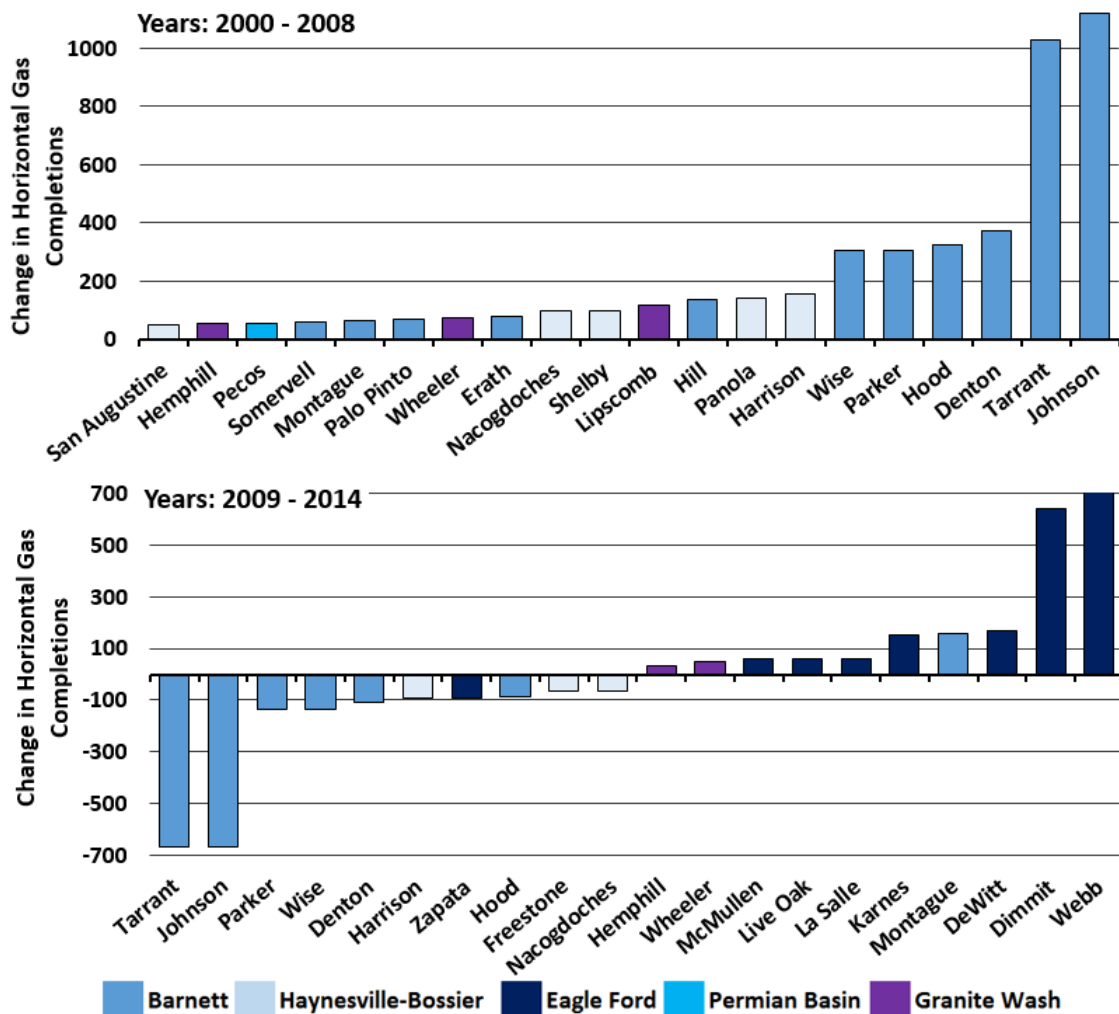


Figure 4.1: County shifts in horizontal gas completions for years 2000-2008 (a) and 2009-2014 (b).

Meanwhile, statewide unconventional oil completions experienced limited growth from 2000 through 2008 with a maximum change of less than 70 completions occurring in

the Texas Panhandle (Figure 4.2a). This trend reversed after 2009, with the northern section of the Eagle Ford formation emerging as a dominant unconventional oil play within the state (Figure 4.2b). Counties that straddle the Eagle Ford Shale along the oil-gas boundary (e.g. Dimmit, McMullen, and La Salle) have observed rapid increases in both oil and gas drilling. By 2012, the Eagle Ford Shale surpassed the Bakken Shale of North Dakota as the primary unconventional oil producer in the U.S. (EIA, 2014d).

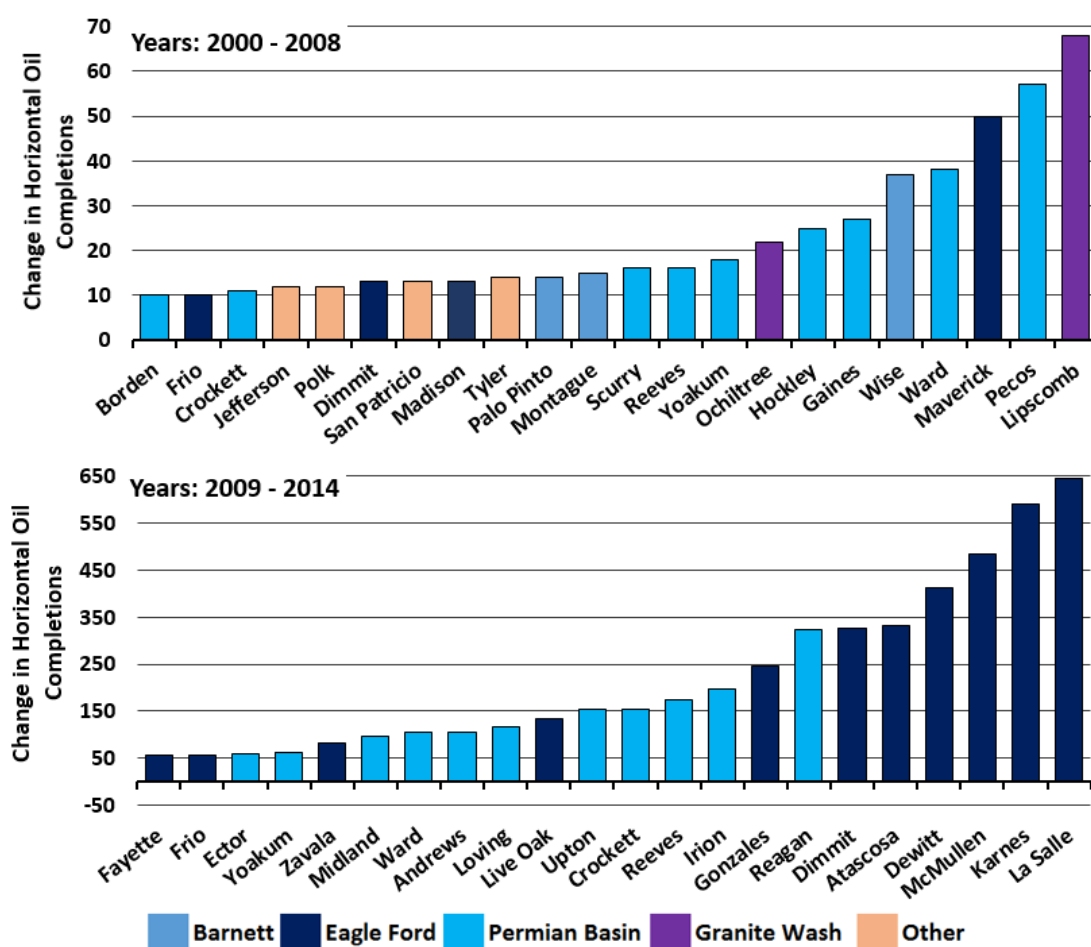


Figure 4.2: County shifts in horizontal oil completions for years 2000-2008 (a) and 2009-2014 (b).

An equally significant aspect of these developments was the drilling activity that occurred within the Permian Basin of West Texas. This region has historically played a prominent role in Texas conventional oil production (Figure 4.3a). From 2009 through 2014, the Permian Basin continued to expand in oil operations, matching the gains observed in the Eagle Ford region (Figure 4.3b). Although initially the Permian Basin was mostly characterized by vertical well completions, since early 2013 there has been a noticeable uptick in horizontal well completions (EIA, 2014e).

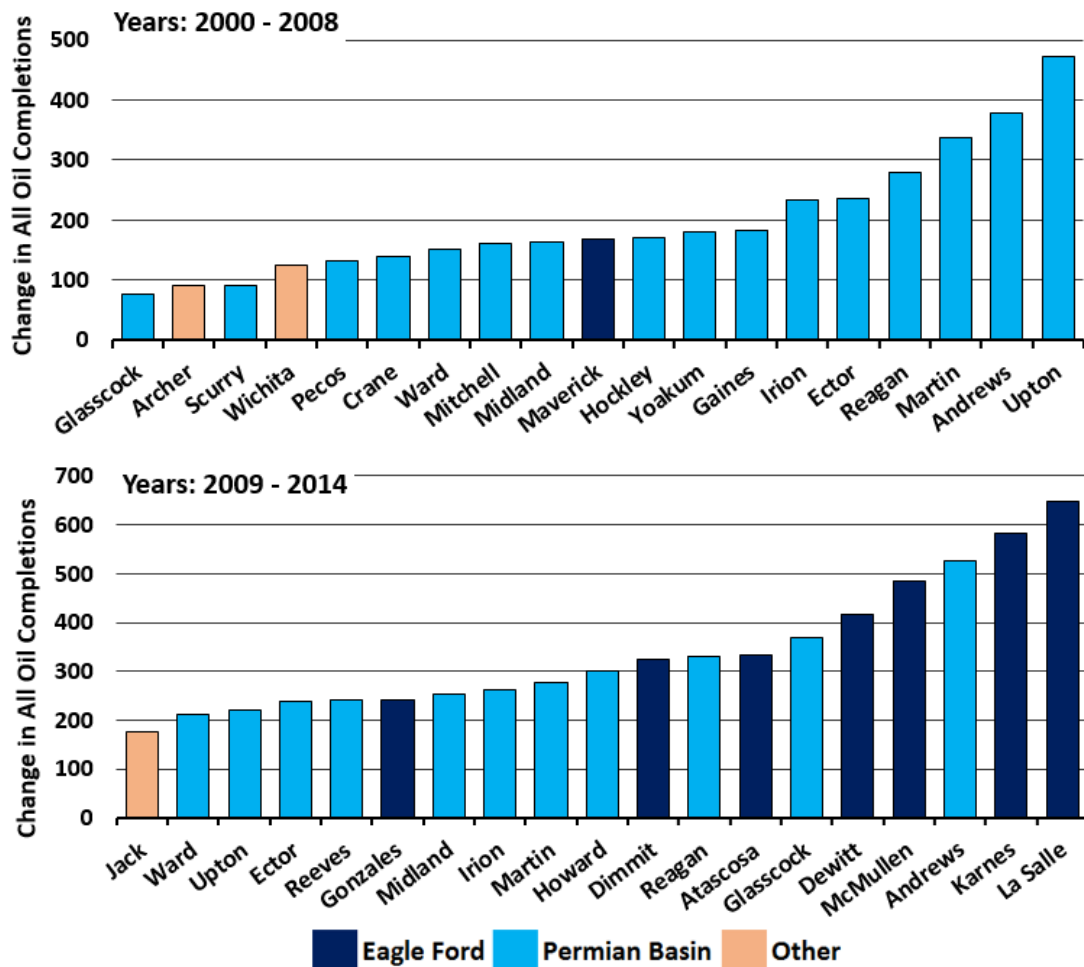


Figure 4.3: Regional shifts among Texas production counties from mostly conventional oil 2000-2008 (a) to more diversified oil 2009-2014 (b).

This robust growth in statewide hydrocarbon production has directly bolstered statewide revenues (TCPA, 2013; The Perryman Group, 2014a). Furthermore, the rapid development followed by a sudden influx of workers and capital has transformed regional, and often rural communities that overlie the hydrocarbon plays (Tunstall et al., 2014; Feyrer, et al., 2014). Because regional shifts are equally, if not more important than the statewide trends, the following chapter focuses on measuring the local economic growth and impacts observed over the last decade.

Chapter 5. Regional Economic Analysis of the Production Counties

Barnett Shale Region – North Texas

The Mississippian (360-325 MA) Barnett Shale of the Fort Worth Basin is an unconventional formation that contains a vast accumulation of non-associated natural gas. The source rock varies from very good (TOC 2-4%) to excellent (TOC > 4%) with regard to its organic richness. Regional expansion of conventional exploration and production started in the early 1980s. In 1990, Mitchell Energy Corp., in collaboration with the Gas Research Institute began actively modeling and defining the characteristics of the reservoir. By 2002, Mitchell Energy successfully drilled five horizontal wellbores with initial production rates of 2.5 - 3.5 MMcfg/day (Bruner and Smosna, 2011). This profitable withdrawal of natural gas from shale launched the recent U.S. hydrocarbon production boom. Most recently, the Barnett Shale was estimated to hold 26.0 TCFG (EIA, 2014f) of proved reserves and 39.0 TCFG of undiscovered, technically recoverable gas. The majority of the recent upstream activity has occurred in the northeastern dry gas ($R_o > 1.2\%$) and condensate ($R_o = 1.0 - 1.2\%$) windows of the play (Bruner and Smosna, 2011).

Prior to analyzing their production and economic trends, the Barnett Shale study counties were subdivided into three categories based on the number of horizontal completions that were achieved from 2000 to 2013 (Figure 5.1). This three-tier classification was intended to provide a comparison between high-production counties that overlay the core hydrocarbon areas and counties that are adjacent to the core areas. The counties that were categorized as *primary* include: Denton, Johnson, Tarrant, and Wise. These primary counties represent approximately 72 percent of horizontal completions between 2000 and 2013. The remaining *secondary* and *tertiary* categories comprise of 9 and 6 counties, representing 26 percent and 2 percent of completions respectively.

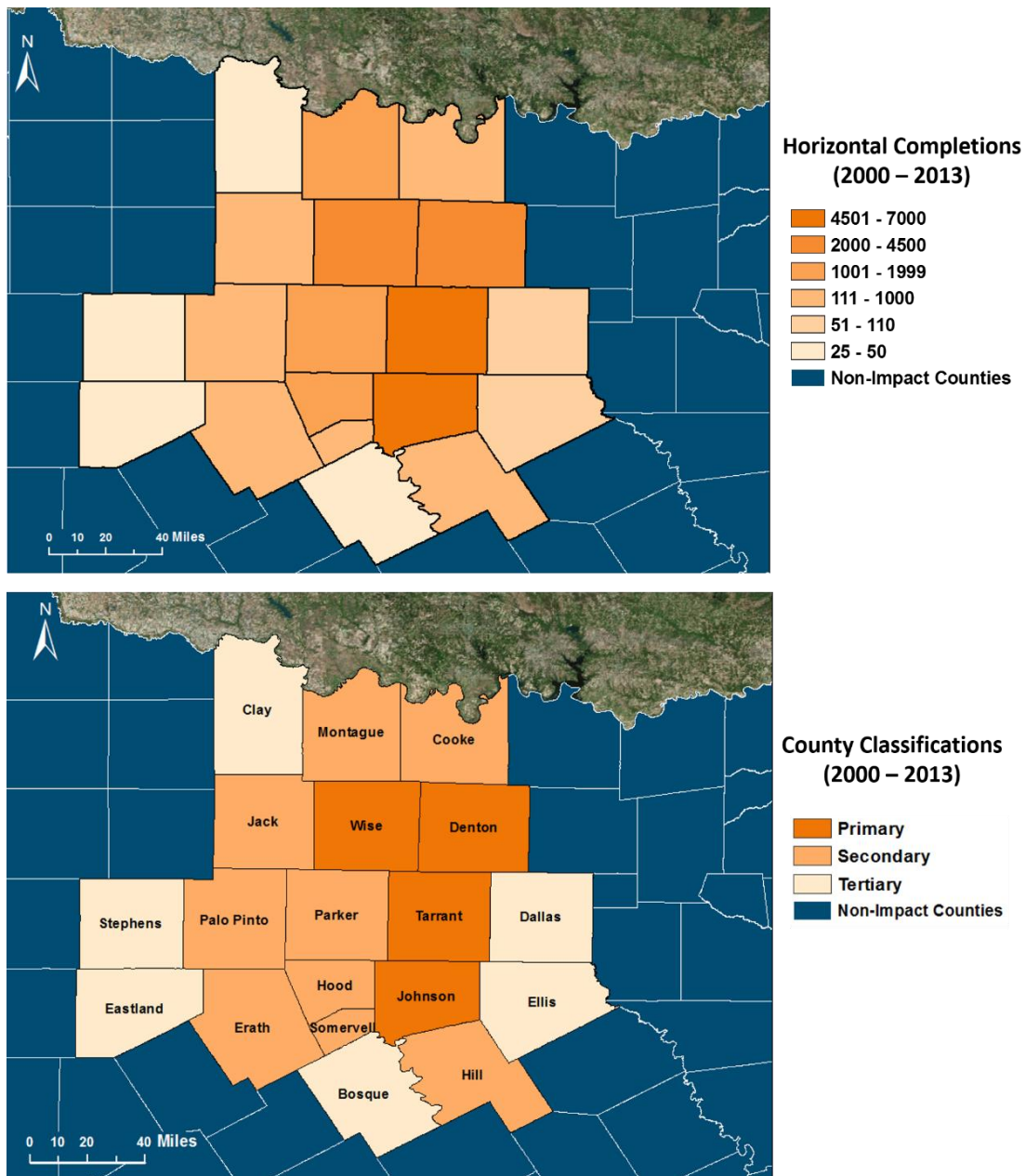


Figure 5.1: Total number of horizontal well completions within counties overlying the Barnett Shale (a) respective county classifications 2000 - 2013 (b).

The Barnett Shale region includes 10 metro, 9 urban, and 0 rural counties, based on the RUCC classification scheme. Dallas County was excluded from the economic analysis because while there were few well completions in this county, it has a large economic

footprint driven by various non-mining industries. While Tarrant County is also home to a major economic center - Fort Worth - the county was included in the analysis because it represented one of the primary production counties.

Horizontal drilling in shales is a relatively nascent process that did not become common in the Barnett Shale area until 2003 (DOE, 2011). By 2005, the industry completed more horizontal wells than vertical wells within the formation (Figure 5.2). The number of gas completions mirrored the increasing price of natural gas (Figure 5.3).

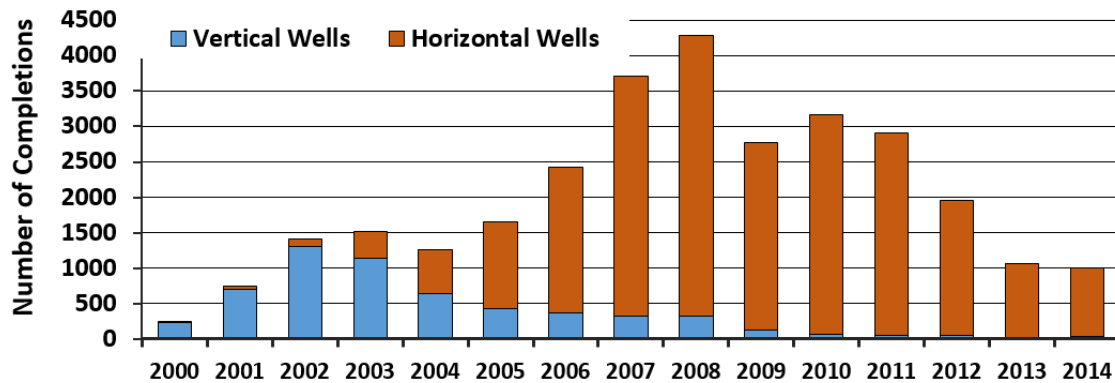


Figure 5.2: Annual comparison between the number of vertical and horizontal well completions in the Barnett Shale area.

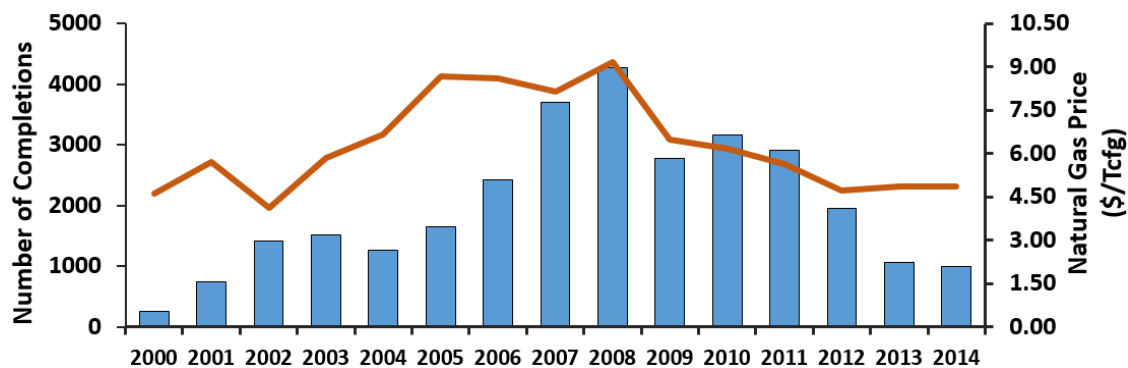


Figure 5.3: Annual comparison between the total number of gas completions (bars) and the respective Citygate price of natural gas (line) in the Barnett Shale area.

As illustrated in Figure 5.3, a lag occurred between the annual number of Barnett well completions and the price of natural gas from 2000 through 2006. Whereas, the other formations displayed a closer relationship between the annual commodity price and the respective number of completions. This lag was likely caused by the delay in technological expansion of horizontal drilling and hydraulic fracturing.

Employment and Wages in the Barnett Region

The Barnett area counties witnessed rapid growth in gas exploration from 2003 through 2008. During this period, employment increased by 17 percent compared to the near-zero percent stagnation of 2000-2003. Promptly after this expansion, the wellhead price of natural gas collapsed by 54 percent from \$7.97/MCF in 2008 to \$3.67/MCF in 2009 (EIA, 2014). The sudden price collapse coincided with the 2008 financial crisis and the coincident decrease in demand for all commodities. Overall local employment declined by three percent and plateaued for the following year. Starting in 2010, the region continued to face slower economic development in urban counties as opposed to the metropolitan-level counties. Throughout the entire timeframe, employment growth in the regional metropolitan counties outpaced that of urban counties (Figure 5.4).

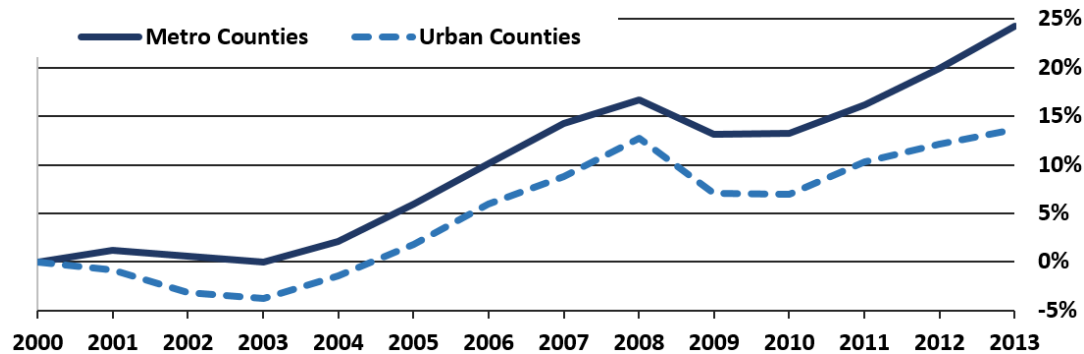


Figure 5.4: Employment growth rate comparison between the regional metropolitan and urban size counties in the Barnett Shale area.

Beginning in 2005, employment in counties with higher exploration activity began outpacing that of counties with lower activity. This divergence became evident by 2008. For example, all of the Barnett counties displayed near-zero percent job growth from 2000 to 2004. By 2008, jobs in the primary, secondary, and tertiary counties expanded by 16, 26, and 12 percent respectively (Figure 5.5). Conversely, between 2009 and 2013, all counties witnessed approximately 10 percent growth in jobs. The rate of employment in secondary-tier production counties notably exceeded that of the primary-tier counties. The main factor that is attributed to this separation is the inclusion of Tarrant County in the analysis. When this populous county is excluded, the remaining primary-tier counties outpace their regional counterparts by as much as 25 percent in job growth. Furthermore, the exclusion of this county increases the total local job growth to 44 percent, thus highlighting the magnitude of the economic effect on the rural counties. This population-based disparity is an important factor to consider, especially because the remaining economic comparisons incorporate Tarrant County due to its large share of gas production.

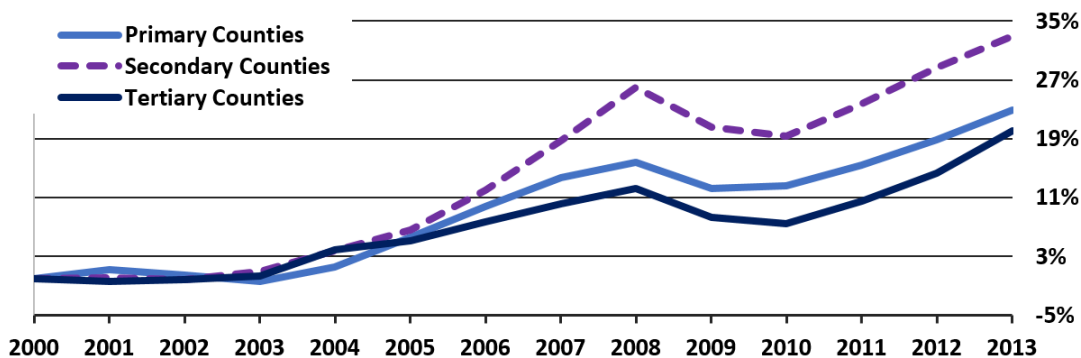


Figure 5.5: Annual employment growth rate comparison between the three classification tiers of gas production counties in the Barnett Shale area.

After 2003, the regional employment growth rate started to deviate from the statewide employment trends. From 2000 until 2008, the average employment in non-

Barnett Texas counties grew by 11 percent. While, employment within the Barnett Shale area counties expanded by 16 percent⁴. This five percent gap in employment continued to slowly increase to seven percent by 2013 (Figure 5.6). Additionally, it should be noted that throughout the study timeframe, the entire Texas employment sector continually outpaced the national trends (TCPA, 2014). Thus, during the study period, the Barnett jobs grew more rapidly than the national average by a notable margin.

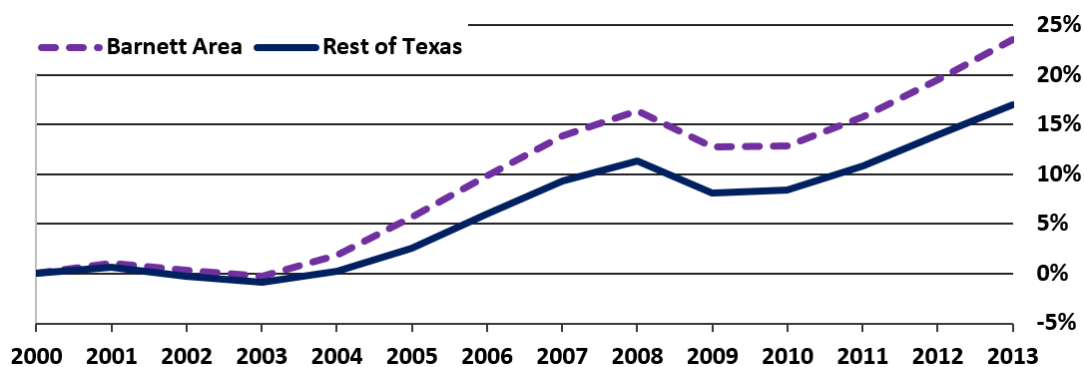


Figure 5.6: Total annual employment growth rate comparison between the Barnett Shale area counties and the rest of the state counties.

Similar to the observations of Maniloff and Mastromonaco (2014) at the national level, the largest growth in the Barnett Shale area was seen in the mining sector. During the period of rapid expansion in gas development between 2004 and 2008, the local mining sector employment rose by 108 percent. This is a prominent shift compared to the 17 percent growth of mining employment observed over the previous four years. The vast majority of additional mining jobs was contained in the primary and secondary-tier production counties, showing increases of 109 and 131 percent in mining-related jobs respectively. In fact, the designated tertiary counties only experienced a 22 percent uptick in mining employment from 2004 to 2008. Following the price collapse, the entire local

⁴ If Tarrant County is excluded from the calculation, then the Barnett-area employment growth between 2000 and 2008 increases to 32 percent.

mining sector contracted by 16 percent before continuing to slowly grow, eventually expanding by approximately 48 percent from 2009 through 2013.

Although Maniloff and Mastromonaco (2014) stated that shale production can have some impact on Construction sector employment, in this thesis, it is assumed that the steep pre-recession ramp-up and subsequent drop in 2009 in local construction jobs was mostly driven by the housing boom and recession. As might be anticipated, the sector expanded rapidly prior to 2008. Following the housing crash, the sector sharply contracted and continued to decline until 2012. Whereas, the Financial Activities sector showed continued gains, even during the recession. Meanwhile, the Professional & Business Services sector required three years to reach the pre-recession job level while the Trade, Transportation and Utilities sector did not reach a pre-recession level until 2013 (Figure 5.7).

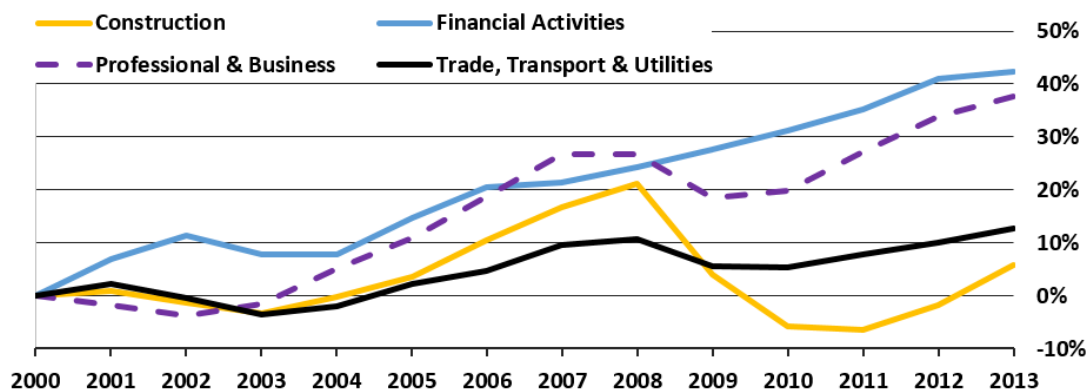


Figure 5.7: Comparison of annual employment growth among the major industries - with the Mining sector excluded - in the Barnett Shale area.

A summary of growth rates in weekly wages by industry in the Barnett area is provided in Figure 5.8. The local Mining sector experienced the largest gains in wages, followed by Financial Activities, then the Construction and Professional/Business sectors. The Trade, Transport and Utilities sector showed limited growth. Since 2009, aside from

Mining, all the major sectors expanded by approximately 20 percent in average weekly wages. Meanwhile, the Mining wages increased by 32 percent. The overall average Barnett Shale area weekly wages did not significantly deviate from the statewide trends. During the entire timeframe, the average weekly wages grew by 60 percent for both, the Barnett area and the rest of the state. As indicated in Figure 5.9, comparison between the statewide and the Barnett area mining wages displays a gap that started to expand in 2006. This gap was influenced by factors like the 2008 financial crisis as well as the increasing mining wages in other hydrocarbon production areas of the state.

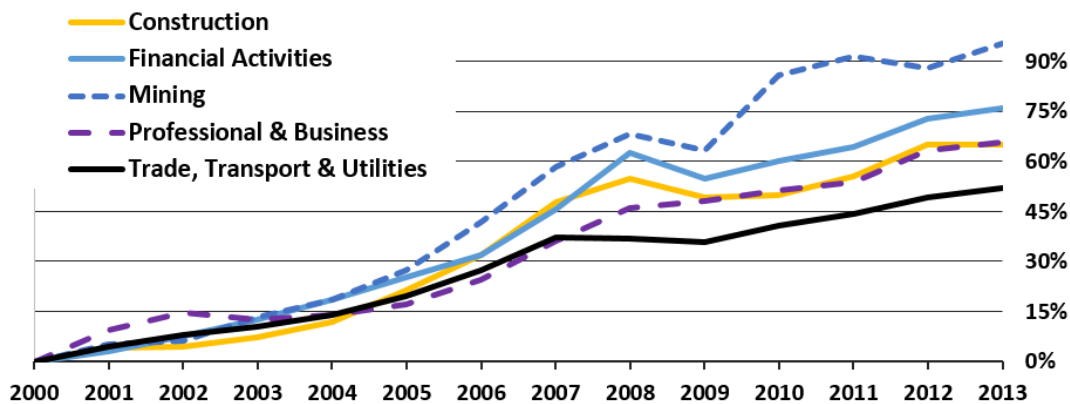


Figure 5.8: Annual comparison of the average weekly wage growth between major industries in the Barnett Shale area.

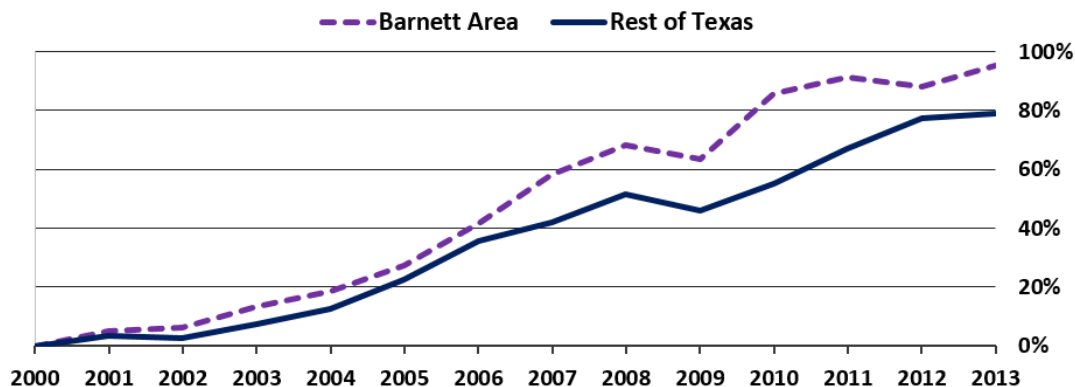


Figure 5.9: Annual comparison of the total average weekly wage growth in the Mining sector between the Barnett Shale area and the rest of the state.

Public Revenues and Expenditures in the Barnett Region

Having considered the employment and weekly wage trends, additional focus was placed on county level spending and earnings. Gross sales data was analyzed in order to capture the general revenue patterns of the entire Barnett region. Essentially, trends in local gross sales may be one of the most important gauges for assessing county revenues because sales taxes are levied by county governments as a means to fund public services and infrastructure projects like parks, hospitals, libraries, and courthouses. The county sales analysis follows a somewhat similar trend as was observed in the employment analysis. Between 2005 and 2008, the primary and especially secondary Barnett Shale area counties began outpacing their adjacent neighbors in annual gross sales (Figure 5.10).

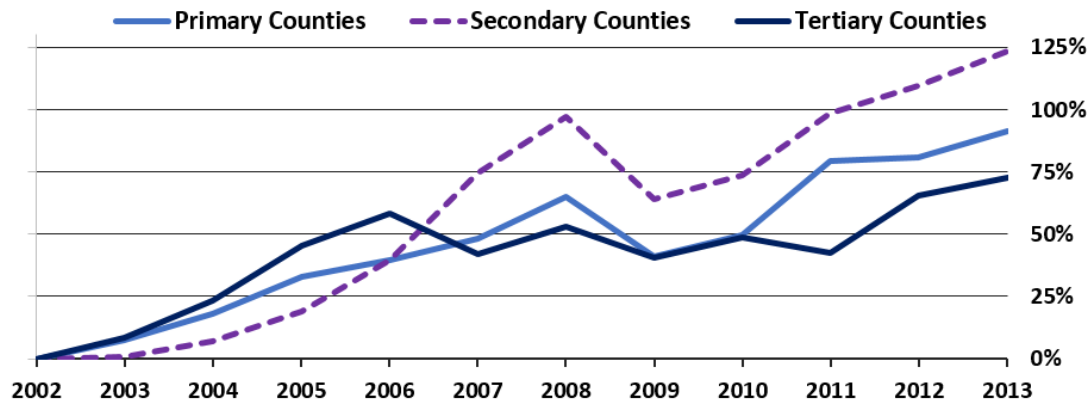


Figure 5.10: Annual gross sales comparison between the three production county classification tiers in the Barnett Shale area. Note: removal of Tarrant County from the analysis reverses the primary and secondary-tier county sales trends.

Compared to the other sectors, the Mining sector in the Barnett Shale area observed the highest growth rate in sales. Although the sector only represents a minor segment of the gross sales (~ 2 percent), its growth can propagate to other economic areas. Annual sales in the Mining sector increased by 950 percent from 2002 to 2008. Meanwhile,

wholesale trade increased by approximately 140 percent. In contrast, retail sales showed a much lower rate of 56 percent from 2000 to 2008 (Figure 5.11). However, if Tarrant County is excluded from the calculation, then the retail sales growth rate increases to 108 percent during the same timeframe.

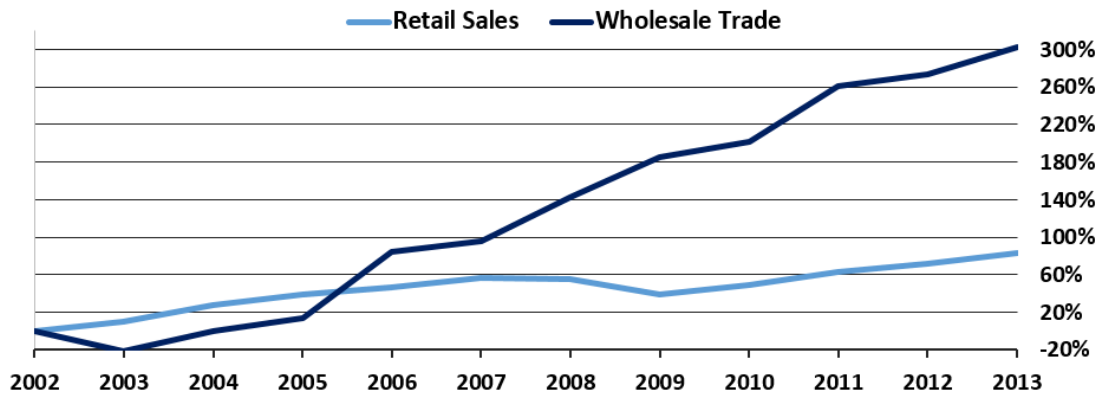


Figure 5.11: Annual sales growth comparison between retail and wholesale trade in the Barnett Shale area.

With Tarrant County included, comparison between the Barnett Shale area and the rest of the state shows a gap in retail sales that expanded from four percent in 2003 to 20 percent in 2007, followed by a convergence in 2008. The regional and statewide retail sales trends diverged again after 2009 by a smaller margin. Whereas, the most significant difference observed in wholesale trade was during the peak of the financial crisis. Despite a sharp statewide decline in 2009, wholesale trade in the Barnett Shale region continued to expand. While on average, the statewide wholesale trade growth was reduced by 28 percent, in the Barnett study area it increased by 18 percent.

Hospitality and Traffic Growth Patterns in the Barnett Region

As mentioned in Chapter 1, the regional hospitality and traffic related trends were analyzed in order to capture some of the effects of rapid growth in local mining jobs. The influx of transient workers associated with an energy boom can indirectly trigger lodging and traffic booms (Nowlin 2011; Allen, 2013). While these developments provide economic benefits, they can also overwhelm local resources, particularly in areas with insufficient housing and limited roadways. Rapid construction of hotels and RV-parks supplements some of the housing shortages that were observed in the production areas, especially in rural counties.⁵

Hospitality related establishments in the Barnett Shale region witnessed a 22 percent increase in hotel room nights-sold during the production boom, followed by an 11 percent decrease in 2009. Afterwards, the number of nights-sold continued to increase by 23 percent to 2013. Comparison between the statewide hospitality trends and the Barnett Shale area indicates minimal, if any, variation. This pattern is noticeably different than what was observed in the Eagle Ford Shale and the Permian Basin regions (see Sections 5.3 and 5.4). Further discussion on the differences between regional hospitality trends is provided in Chapter 8.

In addition to rapid expansion of housing, rural communities may also undergo considerable changes in local traffic volumes. As a result, rural towns that are accustomed to low traffic volumes must upgrade existing infrastructure.⁶ Additionally, increased tanker truck traffic in high drilling activity regions has been linked to increased traffic accidents (Graham, et al., 2015; Muehlenbachs and Krupnick, 2014). Therefore, traffic related

⁵ Based on personal observation of extensive hotel, RV-park, and man-camp construction in production counties.

⁶ Based on personal observation of upgrades made to rural highways within high-level production areas (e.g. installation of traffic lights and addition of traffic lanes).

expenses and damages were reviewed because they serve as an important gauge of the impact of increased energy development.

The rapid increases in heavy-truck traffic have structurally impacted the rural low-volume roads in the Barnett Shale and other hydrocarbon play areas. These Farm-to-Market roads are not accustomed to heavy loads and higher traffic volumes that arise from energy development (Miller and Sassin, 2014). Thus, an evaluation of road maintenance expenditures was conducted by analyzing data collected from the Texas County Lateral Road and Bridge Expenditures annual reports as another measure of the local impact of hydrocarbon production in the region.

Tarrant County was excluded from the Barnett Shale area traffic-impact evaluation in order to avoid any bias that may occur when comparing a metroplex to smaller towns. Instead, the influence of Tarrant County on regional traffic accidents and road expenditures is described within the footnotes. Comparison of annual traffic accidents between the Barnett Shale area and the rest of the state represents a somewhat similar trajectory with a gap that sharply increased from 2006 to 2007 but then steadily converged from 2007 until 2013 (Figure 5.12)⁷.

The entire annual rate was primarily driven by the eight metropolitan counties which accounted for 82 percent of all the traffic accidents during the timeframe. The remaining 18 percent of traffic accidents in the nine urban counties was compared to the statewide urban-size county trends. The urban level county comparison indicates a reversal occurring in 2009 between the regional and the statewide traffic accident growth rates (Figure 5.13).

⁷ With Tarrant County included, this gap decreases from 13 percent to 9 percent in 2007 and from 5 percent to 4 percent in 2013.

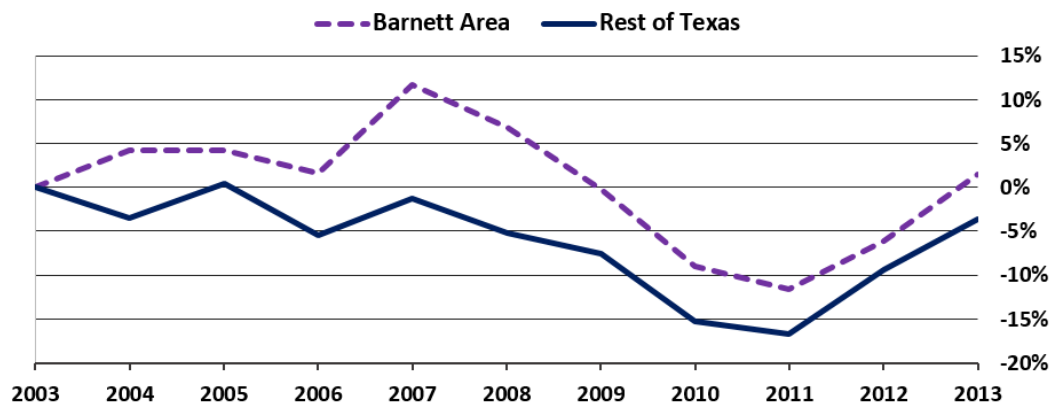


Figure 5.12: Annual traffic accident growth rate comparison between the Barnett Shale area and the rest of the state counties.

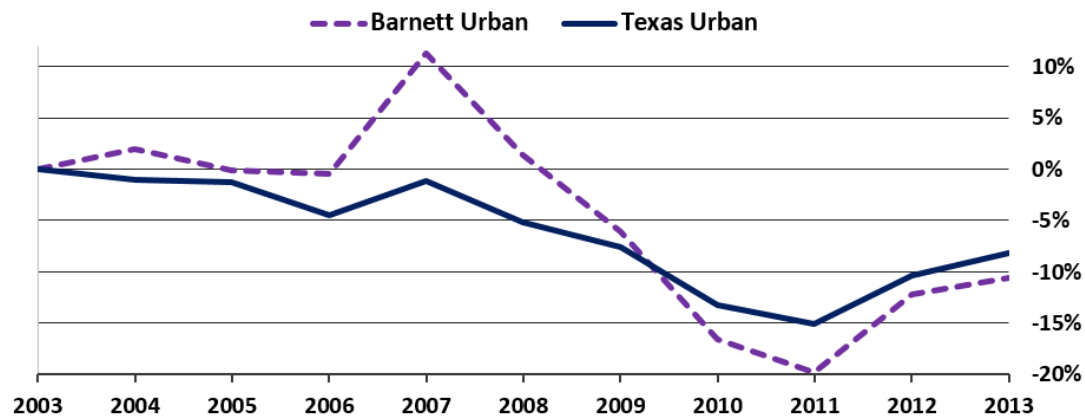


Figure 5.13: Annual traffic accident comparison between the urban counties in the Barnett Shale area and the rest of the Texas urban counties.

The steep decline in traffic accidents observed from 2007 to 2010 is attributed to the 2008 Recession. As Cotti and Tefft (2011) demonstrate, higher unemployment and lower income are associated with a reduction in miles-traveled which translates into fewer accidents. Lastly, while the growth rate of traffic accidents in the Barnett Shale area outpaced the statewide rate, the difference was not nearly as pronounced as that seen in some of the Permian Basin and the Eagle Ford Shale counties (see Sections 5.3 and 5.4). Further discussion on the differences between the regions is provided in Chapter 8.

Finally, county road maintenance expenditure data was combined in order to compare the road expenses of the Barnett area to the rest of the state. Barnett area annual county road expenditures began to diverge from the statewide trends in 2007. By 2013, growth in the Barnett area road costs exceeded statewide growth in expenditures by 59 percent⁸. This wide spread is somewhat misleading due to the disproportionate influence of Parker County which witnessed a large increase in county road expenditures from 2011 to 2013. Expenditure growth in Parker County is not attributed to hydrocarbon development. Exclusion of the county shifts the entire regional trend downwards during the latter part of the timeframe.

As the first economically commercial shale development, the Barnett Shale has generated considerable interest. It is estimated to have generated thousands of jobs and tens of billions of dollars in local and state revenue. Moreover, ongoing production from completed wells continues to provide royalty based income growth (Perryman Group, 2014b). Although the price of natural gas has collapsed, shifting much of the operations towards more profitable oil and NGL-rich formations, the Barnett Shale holds potential for future exploration. It is important to remember that unlike oil, natural gas prices vary globally (FERC, 2014), thus making the commodity attractive for export. As a result, the low price of natural gas has encouraged U.S. developers to retrofit existing LNG import terminals to export LNG instead (Kersley et al., 2012). Inevitably, future market, policy, and commodity price developments will continue defining the regional mining trends of the Barnett Shale area.

⁸ Inclusion of Tarrant County indicates a similar pattern with an average 9 percent increase in expenses occurring from 2004 to 2010. From 2011 to 2013, comparison with or without Tarrant County is nearly identical.

Haynesville-Bossier Shale Region – East Texas

Following the exploration frenzy that occurred in the Barnett Shale, operators began transitioning into other shale formations nationwide. Notably, starting in 2008, there was an increase in horizontal completions in the nearby dry gas-rich Haynesville-Bossier Shale⁹ area of East Texas (Figure 5.14). Commercial exploitation of hydrocarbons from this formation is very recent. In fact, the commonly used term “Haynesville Shale” was originally applied by the Chesapeake Energy Corp. in 2007 (Hammes et al., 2011). It was not until early 2008 that operators realized the potential of the Haynesville Shale for commercial scale gas extraction (RRC, 2014).

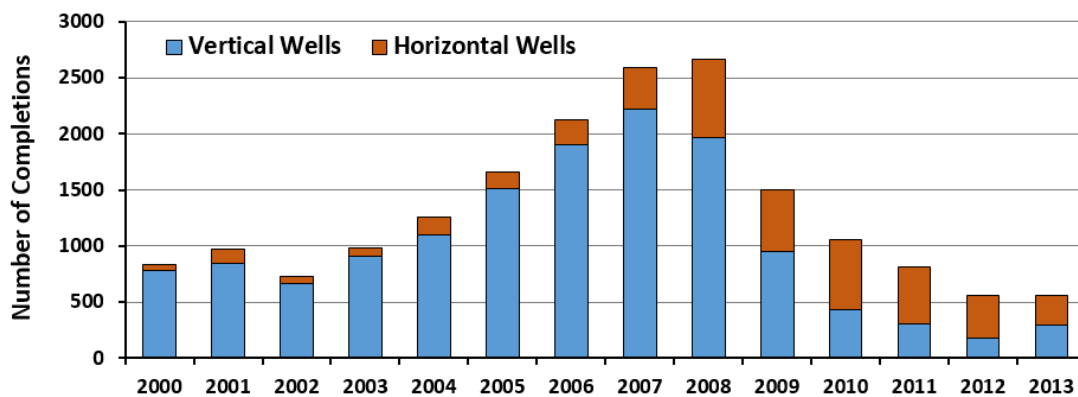


Figure 5.14: Comparison of vertical and horizontal completions in the Haynesville area.

The Upper Jurassic (161-145 MA) Haynesville Shale of the Gulf of Mexico Basin is an organic and carbonate-rich mudrock that straddles the northern section of the Texas-Louisiana border (Parker et al., 2009). Stratigraphically, the shale is underlain by the Smackover Limestone formation and is overlain by the Bossier Shale. While the latter two formations are also potentially viable for hydrocarbon exploration, recently, the focus has been on the Haynesville Shale. This is largely due to the extremely high overpressuring of

⁹ Henceforth, the formations are referred to as the “Haynesville Shale” as this is the most commonly used term.

the shale which results in unusually high initial gas production rates (Stevens and Kuuskraa, 2009; Hammes et al., 2011; Thompson et al., 2011). In regard to its organic content, the Haynesville Shale TOC values range from 0.7 percent to 6.2 percent with an average and median TOC of 2.8 percent (Hammes et al., 2011). Recent evaluations of the shale estimate its proved reserves at 16.1 TCFG (EIA, 2014f) and its undiscovered, technically recoverable gas at 75 TCFG (EIA, 2011).

Development of the Haynesville Shale is nascent, whereas historical natural gas production in the vicinity is well established. Conventional formations like the Cotton Valley and Travis Peak sandstones in East Texas are known sources of natural gas (Dyman and Condon, 2006; Bartberger, et al., 2003). Consequently, the majority of the 2000-2013 regional completions were directed at conventional formations that are adjacent to the Haynesville Shale. This focus on multiple formations contrasts the trend observed in North Texas, where the Barnett Shale served as the primary target for the newly drilled horizontal wells. Additionally, many of the Haynesville area completions were reentry wells¹⁰. The total number of well completions in the Haynesville Shale area only represented 60 percent of the Barnett Shale area completions during the same timeframe. Another contrast was the price-completion relationship which was more pronounced for the Haynesville Shale than for the Barnett Shale. As mentioned in Section 5.1, the lag seen in the Barnett area was likely due to the delay in expansion of new horizontal drilling technology required to exploit unconventional resources. Similar to the Barnett area assessment, the Haynesville Shale counties were subdivided into three classes prior to the analysis, in order to rank each county by level of production (Figure 5.15).

¹⁰ Horizontal or diagonal reentry wells are often utilized in order to revive production from older depleting reservoirs (Hill, et al., 1996). These wells are cheaper to drill due to the shorter lateral distance and existing leases.

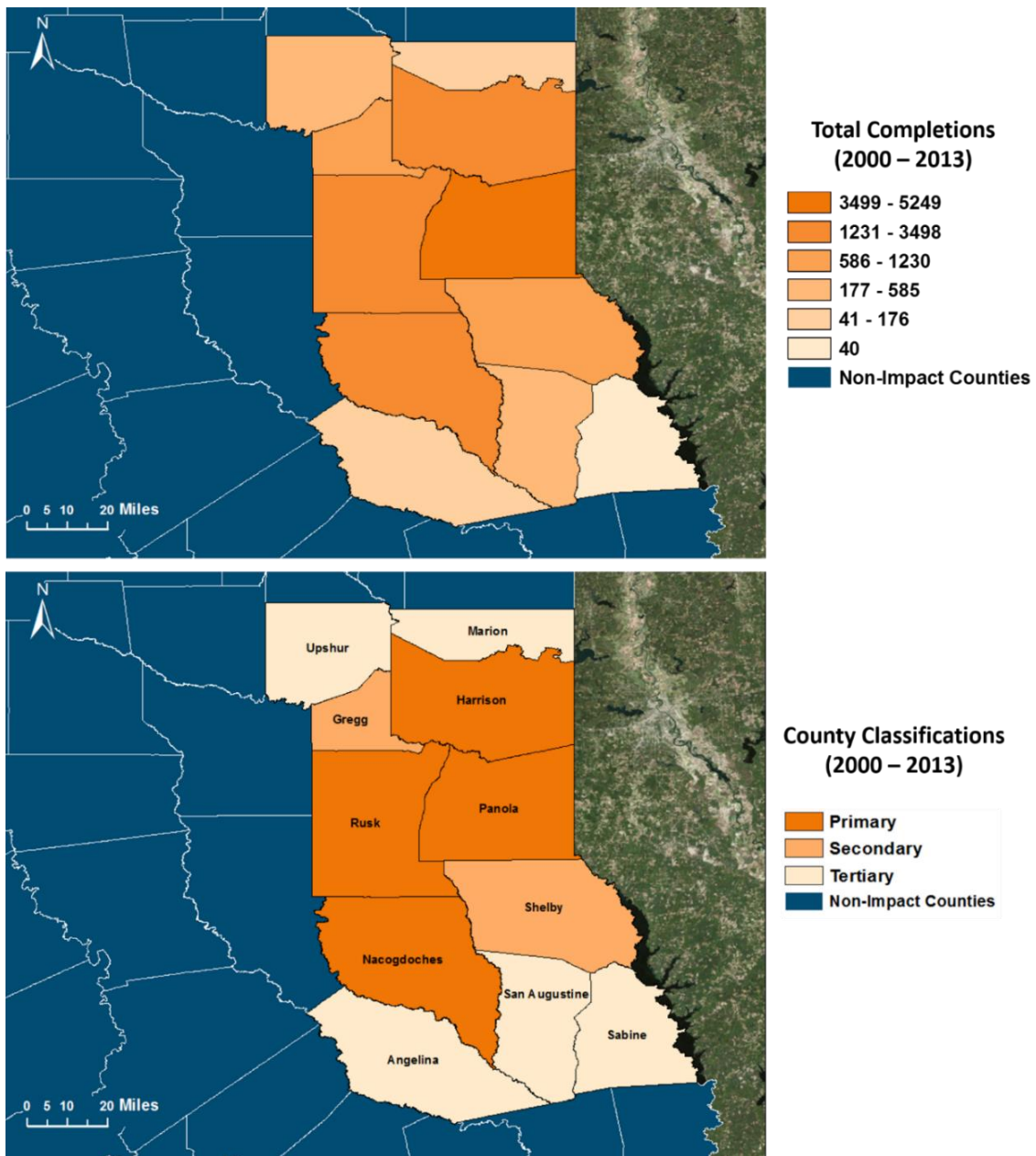


Figure 5.15: Total number of completions within counties overlying the Haynesville Shale (a) and respective county classifications between 2000 and 2013 (b).

Four counties were categorized as *primary* including, Harrison, Nacogdoches, Panola, and Rusk. The four counties represented approximately 79 percent of all the completions between 2000 and 2013. The remaining *secondary* and *tertiary* categories

comprised of 2 and 5 counties, representing 13 percent and 8 percent of completions respectively. The overall Haynesville Shale region includes 3 metro, 5 urban, and 3 rural counties, based on the RUCC classification scheme.

Employment and Wages in the Haynesville Region

Following the pattern seen in the statewide job market, starting in 2005, the Haynesville regional metropolitan counties outpaced the urban and rural counties in total job growth (Figure 5.16). From 2000 until 2008, employment in regional metropolitan counties increased by 16 percent compared to the statewide average of 12 percent. Meanwhile, both Haynesville and the statewide urban counties increased by 8 percent. The largest deviation from the statewide trends in employment was observed within the three rural counties. While statewide rural employment increased by 5 percent from 2000 to 2008, the Haynesville area rural employment declined by 5 percent. By 2013, the negative gap between statewide and Haynesville area employment growth expanded to 5 percent, mostly driven by the negative rate observed in rural counties.

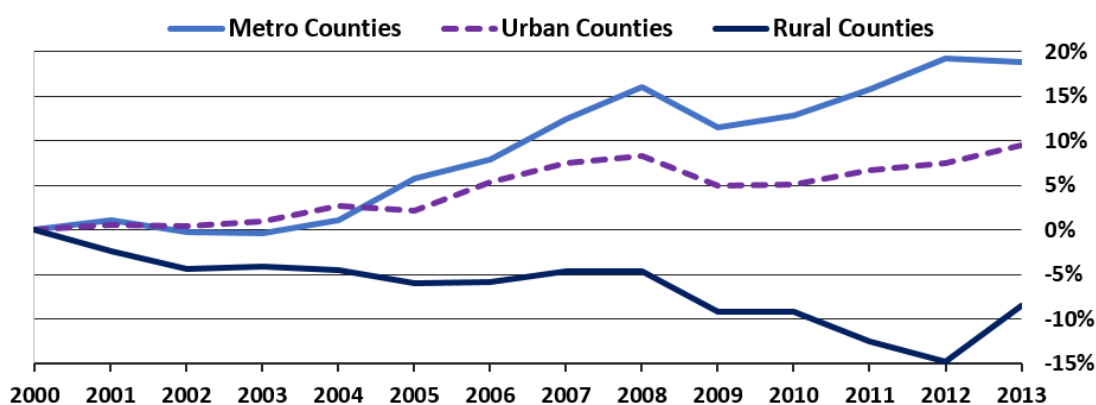


Figure 5.16: Annual employment growth comparison in the Haynesville Shale area by relative county population classifications.

The populations of Haynesville counties are highly correlated with production rankings. Thus, there is little contrast between population and production-based trends in the employment analysis. For instance, jobs in secondary-tier production counties corresponded with growth seen in metro counties. This was due to the influence of Gregg County which holds the largest workforce of all the local counties. Likewise, primary-tier production counties reflect the urban counties because three of the four primary counties were also ranked as urban. Meanwhile, all of the rural counties were classified as tertiary which is also reflected in the analysis (Figure 5.17).

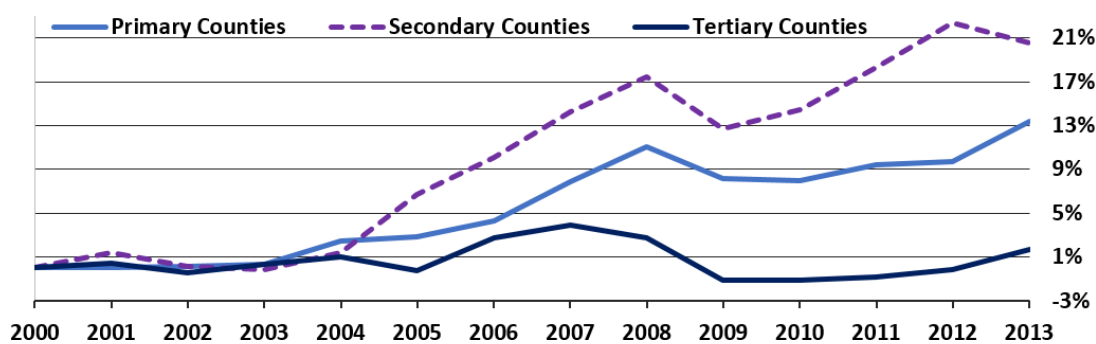


Figure 5.17: Annual employment growth comparison between gas production counties in the Haynesville Shale area.

Altogether, mining showed the highest gains in job growth. While somewhat parallel to the trajectory seen in the Barnett area, the Haynesville mining jobs increased at almost half the rate of the Barnett area. Nonetheless, mining showed the steepest job growth of all the major local industries. Construction in the Haynesville area witnessed a sharp rebound after 2009. This increase in employment was primarily focused in the higher population areas, especially Gregg County, where construction jobs expanded by 139 percent during the timeframe. Meanwhile, the three rural counties faced a 40 percent decline in construction employment. The increase in construction jobs in Gregg County is not attributed to oil and gas production because the number of well completions actually

declined at a steep rate during this period. The regional employment in the Professional & Business sector has stagnated after the 2008 financial crisis while the Financial Activities and the Trade, Transport and Utilities sectors experienced limited growth (Figure 5.18).

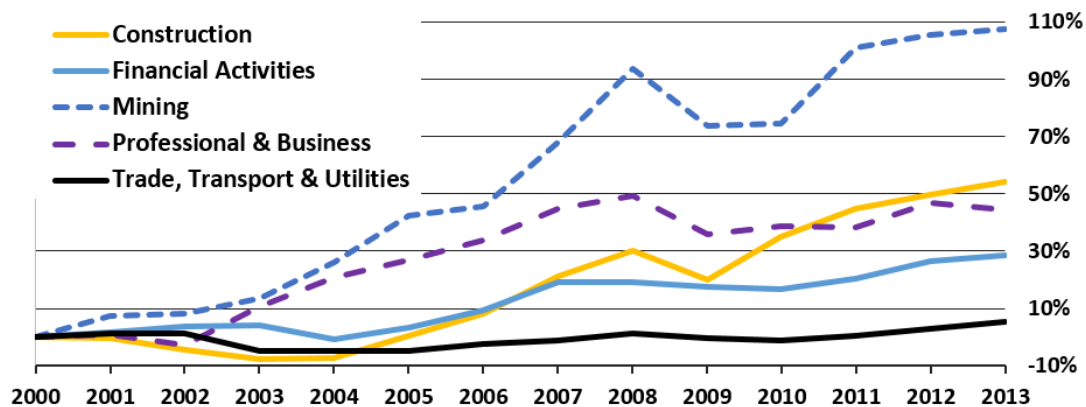


Figure 5.18: Annual employment growth comparison among the major industries in the Haynesville Shale area.

The average weekly wage analysis demonstrated relatively similar trends across the major sectors with the exception of Mining and the Professional & Business (Figure 5.19). These two sectors witnessed notable fluctuations in average weekly wages during the timeframe. Wages in the Mining sector displayed a sluggish growth rate until 2004, followed by an uptick from 2005 to 2008. From 2009 to 2011, mining wages increased at a more rapid pace. This growth coincided with a sharp increase in Haynesville Shale-targeted completions. However, the Haynesville area lagged behind the rest of the state in respect to the overall growth in mining wages. Initially, from 2000 to 2001, the area followed the statewide trend before diverting from 2001 through 2008. By 2008, the continued negative margin between Haynesville area mining wages and the statewide average increased by 27 percent (Figure 5.20).

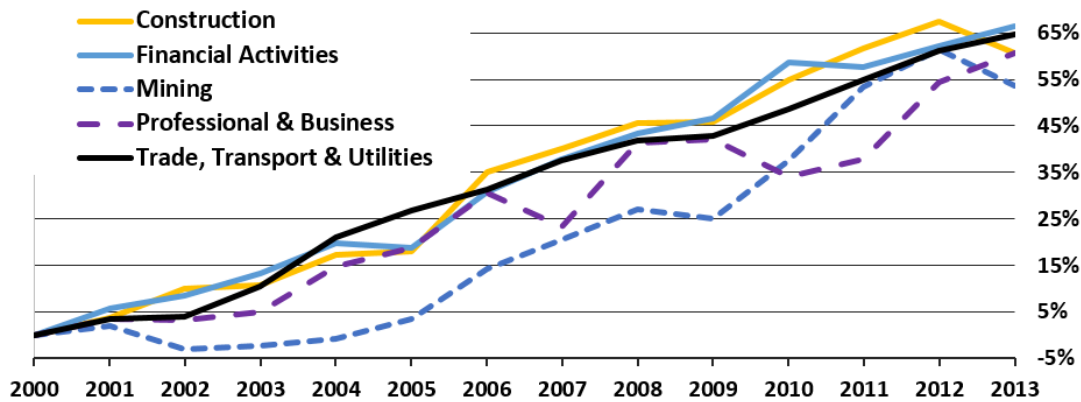


Figure 5.19: Annual average weekly wage growth comparison by industry in the Haynesville Shale area.

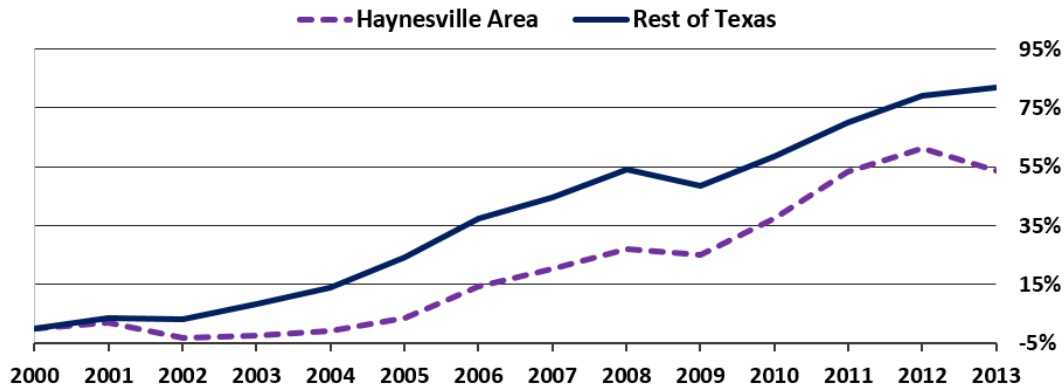


Figure 5.20: Annual Mining sector wage growth comparison between the Haynesville Shale area and the rest of the state.

Public Revenues and Expenditures in the Haynesville Region

Gross sales in the Haynesville area closely matched the pattern seen throughout the state. This corresponding trend was primarily influenced by the more populated regional counties. The metropolitan-ranked Gregg County showed the highest growth rate of 123 percent from 2002 to 2008, followed by a recession-driven contraction. From 2009 to 2013, Gregg County gross sales continued to increase by 80 percent. Meanwhile, gross sales in the five urban-ranked counties increased by 72 percent from 2000 to 2008, followed by a 28 percent decline in 2009 and a stagnant oscillation of less than five percent from 2011 to

2013. The three local rural counties experienced the slowest gains in sales. After increasing by 38 percent from 2002 to 2004, the rural counties began to decline in gross sales, with an overall 19 percent decrease from 2004 to 2013.

Resembling the pattern of the Barnett Shale area, the Haynesville Shale area Mining sector showed the highest increase in sales. Unlike the Barnett area, sales in wholesale trade of the Haynesville region steadily declined from 2008 to 2009 and again from 2011 through 2013 (Figure 5.21). Even when compared to the statewide average, the local wholesale trade lagged behind. This is especially evident in the latter part of the timeframe. From 2009 to 2013, the Haynesville area wholesale growth rate rapidly began to diverge from the statewide rate. By 2013, the growth in regional wholesale trade sales was 114 percent behind the rest of the state counties. This discontinuity is starkly distinct from what was observed in North Texas where wholesale trade sales outpaced the statewide average, particularly during the financial crisis.



Figure 5.21: Annual sales growth comparison between retail and wholesale trade in the Haynesville Shale area.

While there was a stark difference in wholesale trade between the Barnett and Haynesville regions, comparison of retail sales indicated a relatively similar pattern. This pattern showed a continuous gap that steadily increased from six percent in 2003 to 35

percent in 2013 (Figure 5.22). In summary, the Haynesville Shale area experienced lower growth in wholesale and retail trade than the rest of the state. Furthermore, when compared to the Barnett Shale area, there was significant negative growth in retail, and especially wholesale growth. Although, when all other sector sales were included, the Haynesville area gross sales matched the statewide growth trend. This was primarily influenced by growth occurring in Gregg County¹¹.

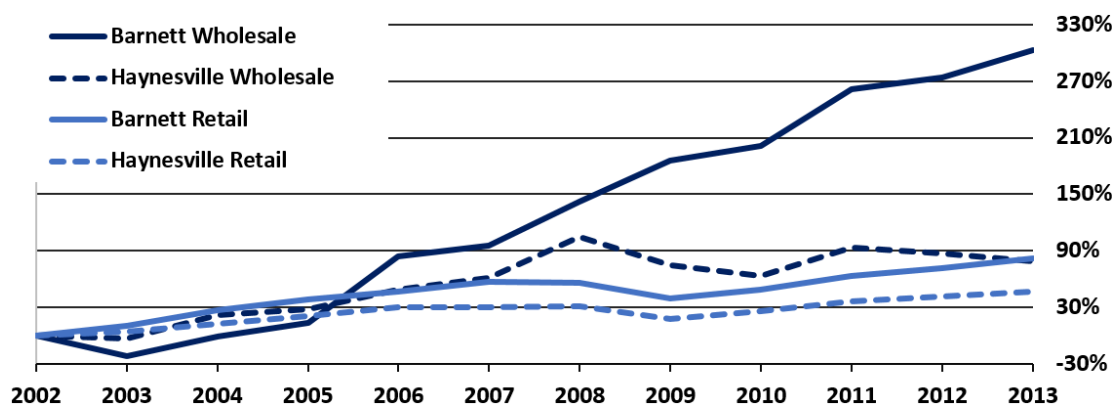


Figure 5.22: Comparison of growth in annual wholesale and retail sales between the Barnett and the Haynesville areas.

Hospitality and Traffic Growth Patterns in the Haynesville Region

In regard to the hospitality trends, from 2004 to 2010, the Haynesville area exceeded the rest of the state in additional hotel room nights-sold by 12 percent. In 2010, this separation began to decrease, with the statewide rate surpassing the Haynesville area rate in 2011 (Figure 5.23). The growth in hotel revenue followed suit, with statewide growth rate in hotel revenue exceeding the Haynesville area by 25 percent in 2013. The influence of Gregg County that was observed in the sales data, is less apparent in the hospitality analysis. In fact, much of the regional increases in hotel nights-sold is driven by the primary production counties (Figure 5.24). As previously mentioned in the Barnett area

¹¹ As mentioned previously, Gregg County is the most populous county in the Haynesville area.

analysis, the hospitality trends do not exhibit a clear pattern in regards to oil and gas activity. In Chapter 8, a comparison is provided between the Haynesville area and other producing regions like the Permian Basin and Eagle Ford.

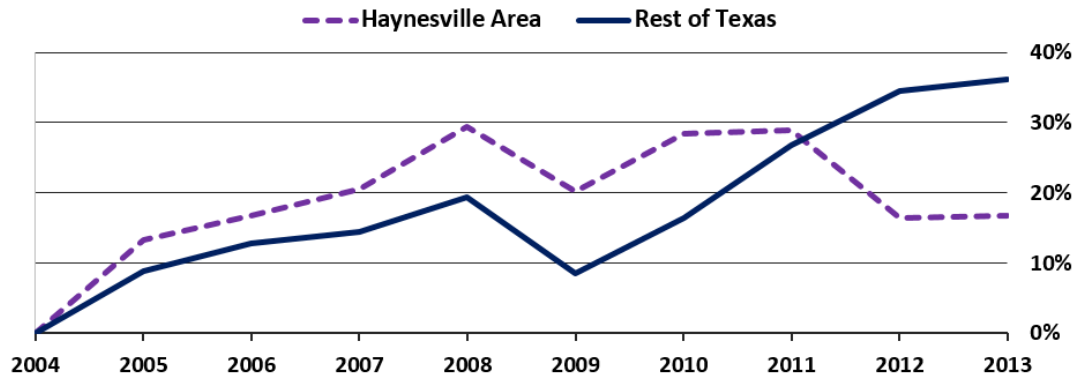


Figure 5.23: Annual comparison of the growth in hotel room nights-sold between the Haynesville Shale area and the rest of the state.

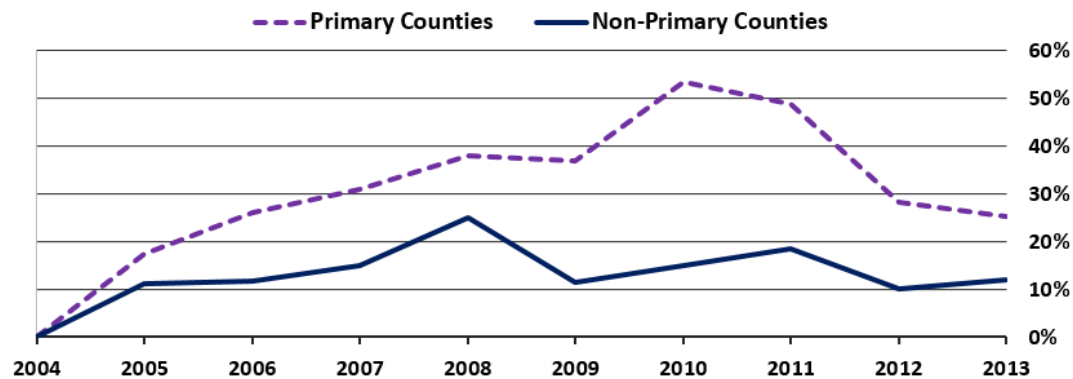


Figure 5.24: Hotel room nights-sold growth comparison between the primary and non-primary production counties in the Haynesville Shale area.

The overall traffic accident rate in the Haynesville area followed the statewide trend from 2003 to 2008. From 2008 to 2009, regional traffic accidents sharply declined. This sharp drop coincides with the recession¹² and is attributed to Gregg County which

¹² As mentioned in the Barnett Shale analysis section, the 2008 Recession placed downward pressure on the overall growth in traffic accidents.

experienced a 47 percent decline in traffic accidents from year-to-year. Concurrently, the lower population primary-ranked production counties declined at a similar rate as the rest of the state. Following the recession, the entire region continued to witness lower numbers of traffic accidents (Figure 5.25). Meanwhile, local road expenses showed the highest growth in the two secondary-tier production counties (Figure 5.26).

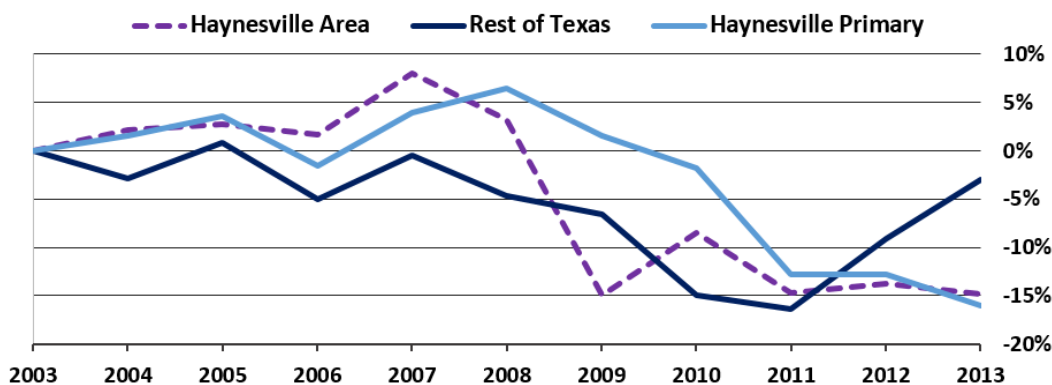


Figure 5.25: Traffic accident comparison between the Haynesville area, the primary Haynesville production counties, and the rest of the state.

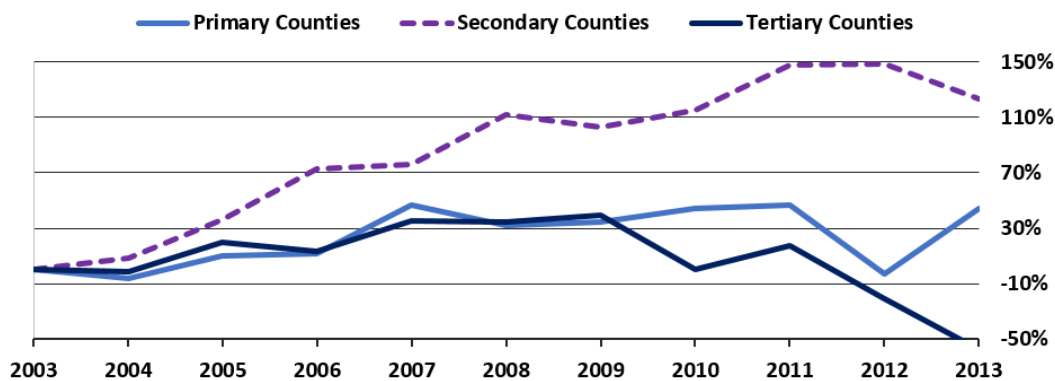


Figure 5.26: Annual growth comparison of county road expenses between the three production county classification tiers in the Haynesville area.

In 2008, the Haynesville Shale witnessed some growth in drilling activity. However, unlike the more gradual decline observed in the nearby Barnett Shale, the

number of completions in the Haynesville area rapidly dropped after the 2009 price collapse of natural gas. Considering the short-lived development of the Haynesville Shale, regional gas extraction trends are more sporadic than in the Barnett Shale where the core production counties were well established. For instance, initial producing wells on the Texas side of the Haynesville formation were drilled in 2008 in the northern Harrison and Panola counties. The reservoir in these areas proved to be of lower quality, therefore, in late 2009 the producers shifted their operations southward where production rates were higher (Thompson et al., 2011). During the study timeframe, the Haynesville area showed the lowest economic expansion of all the study areas. A number of mining-related factors may have contributed to the slower growth. First, the growth in new Haynesville Shale well completions was limited and short-term. Second, the Haynesville Shale is markedly deeper than the Barnett Shale (Bruner and Smosna, 2011; Hammes et al., 2011). This depth difference leads to increased costs that may discourage potential operators from investing. Lastly, the Haynesville area is characterized by dry gas production. This characteristic is shared by both, the Barnett and the Haynesville shales. The low price of dry gas discouraged development of the capital intensive formations. As natural gas prices remained depressed, operators transitioned into the more lucrative oil and NGL-rich shales.

Eagle Ford Shale Region – South Texas

In 2008, the Upper Cretaceous (100 – 66 MA) Eagle Ford formation of the Western Gulf Basin emerged as a prolific unconventional oil and gas play (RRC, 2014). The Eagle Ford Shale stretches across the southernmost segment of the U.S. – Mexico border, underlying a large section of South Texas. Based on the number of well completions, 27 counties were designated for analysis. By applying the completion based classification, 8 counties were categorized as *primary*, 10 as *secondary*, and 9 as *tertiary* (Figure 5.27).

Likewise, by referencing the RUCC classification scheme, 9 counties were classified as metropolitan, 15 as urban, and 3 as rural.

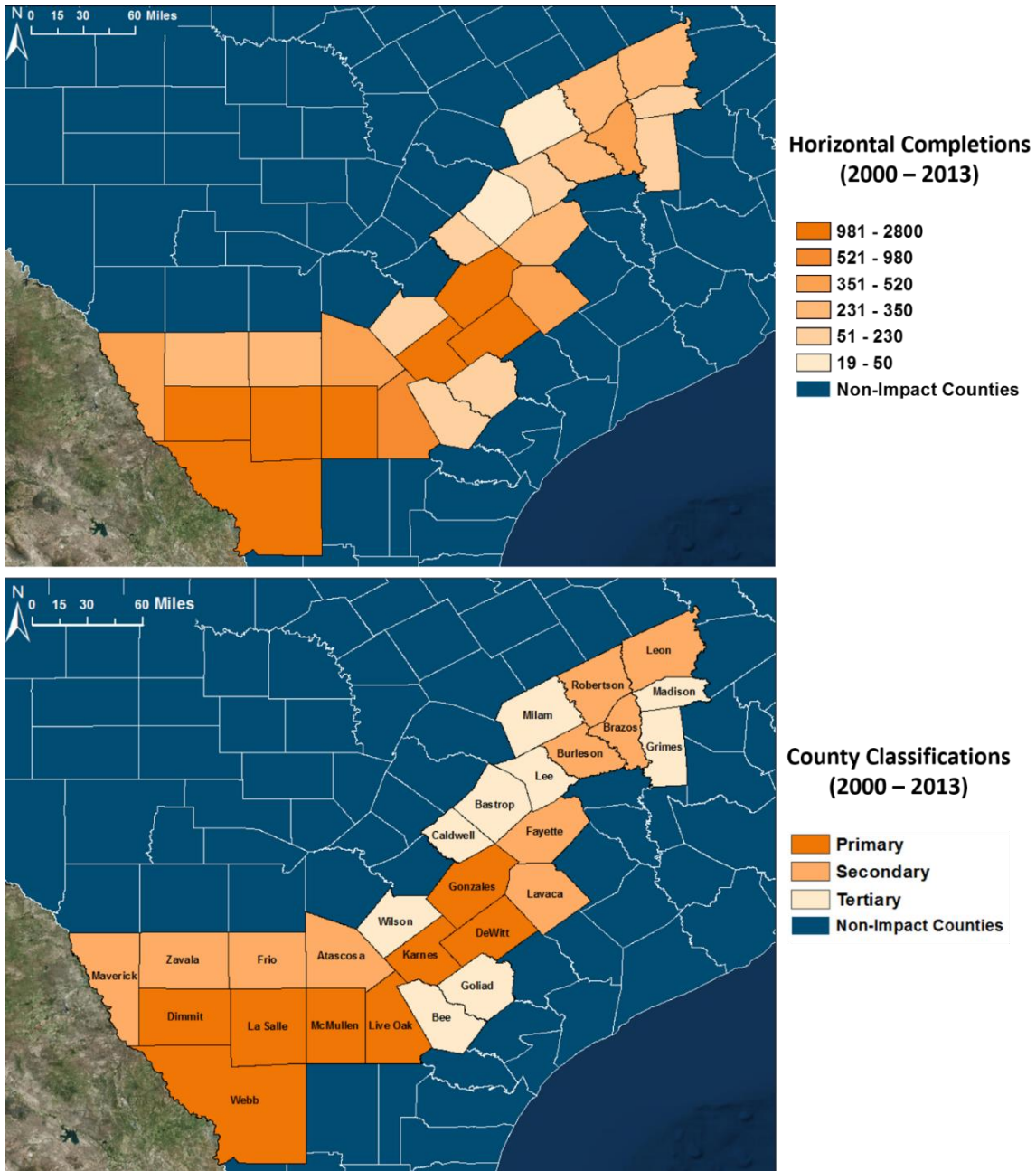


Figure 5.27: Number of horizontal completions in counties overlying the Eagle Ford Shale (a) and respective county classifications between 2000 and 2013 (b).

In regard to its organic content, the Eagle Ford Shale TOC values range from 3.05 percent to 5.0 percent (Harbor, 2011). The shale formation is estimated to hold 17.4 TCFG of proved gas reserves and 4,177 MMBO of proved oil reserves (EIA, 2014f). Additionally, its undiscovered technically recoverable reserves are estimated at 853 MMBO of oil and 1,707 BCFG of gas in the shallower northwestern oil window along with 50,219 BCFG of gas and 2,009 MMBNGL of NGLs in the deeper southeastern gas window. (Dubiel et al., 2012). These adjacent, continuous hydrocarbon windows make the Eagle Ford Shale distinct from other dry gas bearing shales.

In response to the falling natural gas prices, operators quickly transitioned into this lucrative tight oil and gas play. In 2010, there was a stark uptick in horizontal well completions. Since then, the annual number of horizontal well completions has surged, reaching approximately 7000 new completions in 2013 (Figure 5.28). Furthermore, as a result of rising oil prices, much of the growth has been concentrated in the central condensate and northern oil windows of the unconventional formation (Figure 5.29). Initially, much of the development was focused on the regional conventional gas-bearing sandstones. Similar to the pattern observed in the Haynesville region, from 2000 to 2011, South Texas gas well completions closely followed their respective commodity price. These completions were primarily vertical wells that targeted dry gas pockets. Beginning in 2012, gas completions trends sharply deviated from the natural gas price (Figure 5.30). This wide division is primarily attributed to the shift towards NGLs which were priced higher than methane (EIA, 2014c).

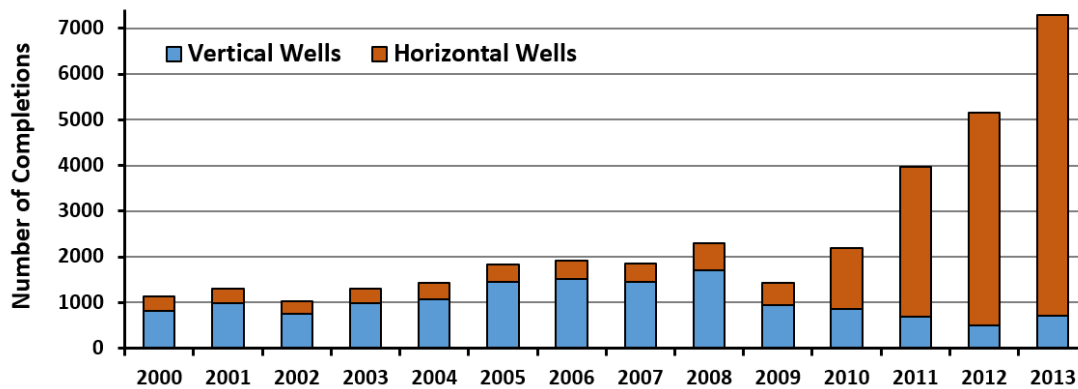


Figure 5.28: Annual comparison between the number of vertical and horizontal well completions within the Eagle Ford Shale area.

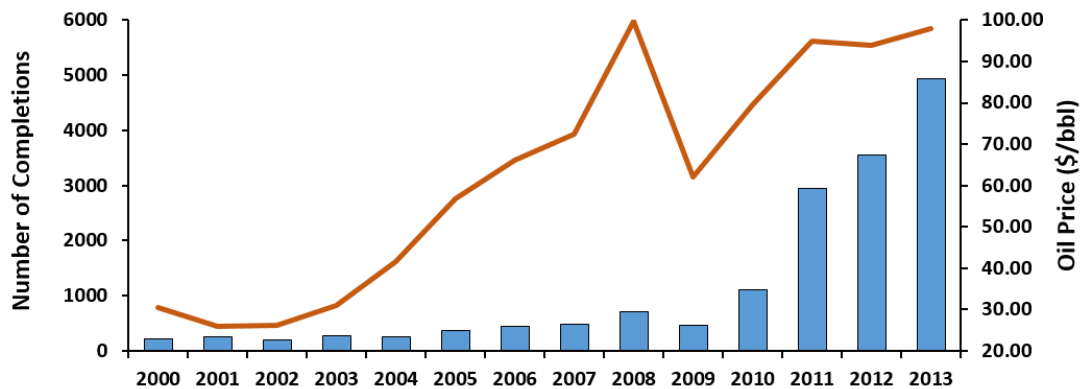


Figure 5.29: Annual comparison between the total number of oil completions (bars) and the respective WTI price of oil (line) in the Eagle Ford Shale area.

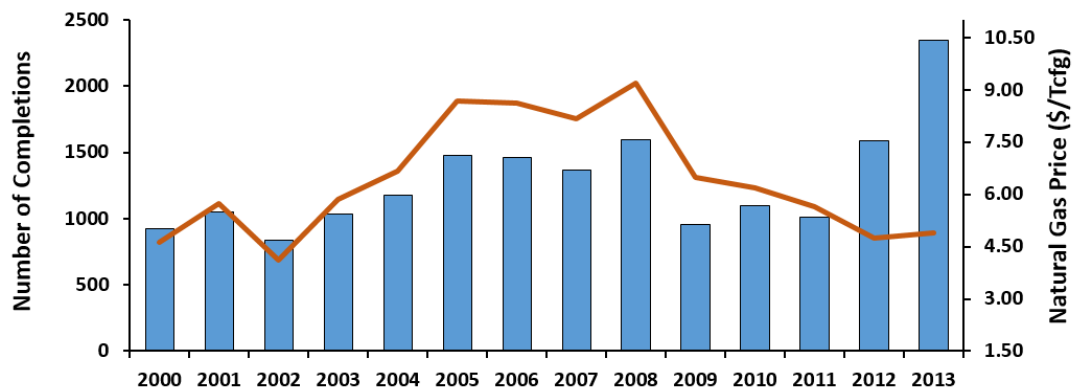


Figure 5.30: Total number of annual gas completions in the Eagle Ford area (bars) compared to the respective Citygate price of natural gas (line).

Employment and Wages in the Eagle Ford Region

The recent surge in production has transformed the historically rural and low income region (Tunstall et al., 2014; Gilmer et al., 2012). This transformation is clearly visible throughout the area.¹³ Annual employment analysis highlights the level of impact on the regional job market. Since 2002, the primary-ranked production counties have experienced the largest gains in jobs. In particular, LaSalle, McMullen, and Dimmit counties have witnessed the sharpest job growth of 159, 152, and 116 percent respectively. These three mostly rural counties are situated in the southern area of the play that overlays the condensate and oil-bearing sections. Meanwhile, the secondary and tertiary-ranked counties have also displayed notable employment expansion. For instance, even during the 2008 financial crisis, the secondary-ranked production counties continued to gradually increase in employment (Figure 5.31).

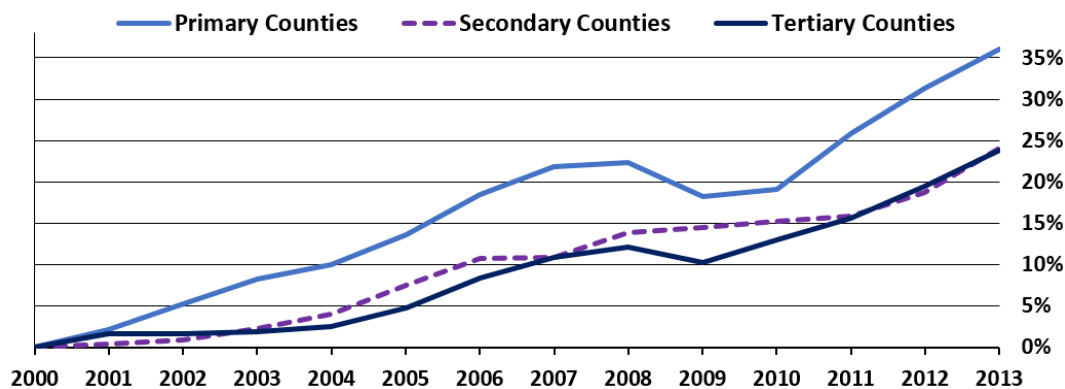


Figure 5.31: Annual employment growth comparison between the three classification tiers of production counties in the Eagle Ford Shale area.

Another important aspect of the surge in Eagle Ford drilling operations was the steep increase in rural employment that followed. By 2012, the three local rural counties

¹³ Based on personal observation of rapid E&P related development in the rural South Texas region (e.g. sharp population growth along with hotel, restaurant, banking, and grocery store construction).

outpaced their metropolitan counterparts in employment growth. This trend is notably different from the statewide pattern where the lowest growth rates occurred in the rural counties. The majority of the urban-ranked Eagle Ford counties experienced consistent gains in jobs from 2009 to 2013 at almost triple the rate of the statewide urban county average (Figure 5.32). Throughout the study period, the Eagle Ford area continuously outpaced the rest of the state in total employment growth with the largest difference of 11 percent occurring in 2013 (Figure 5.33).

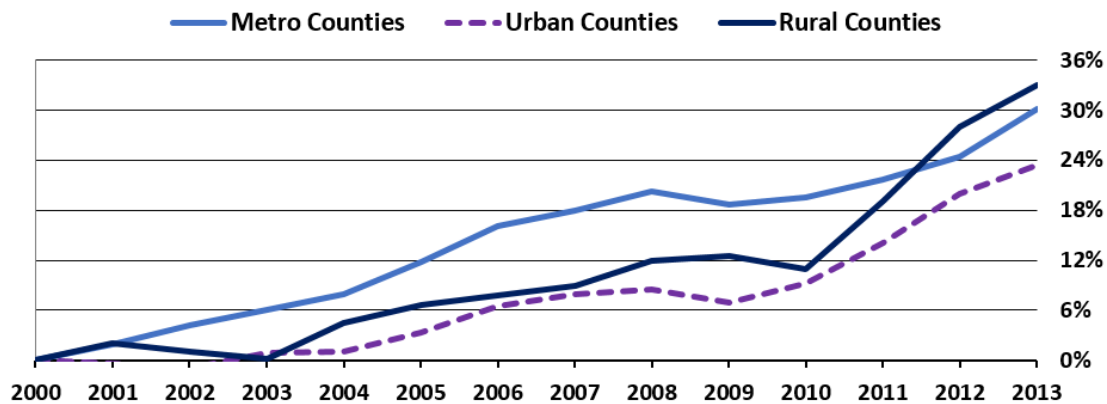


Figure 5.32: Annual employment growth comparison in the Eagle Ford Shale area by relative county populations.

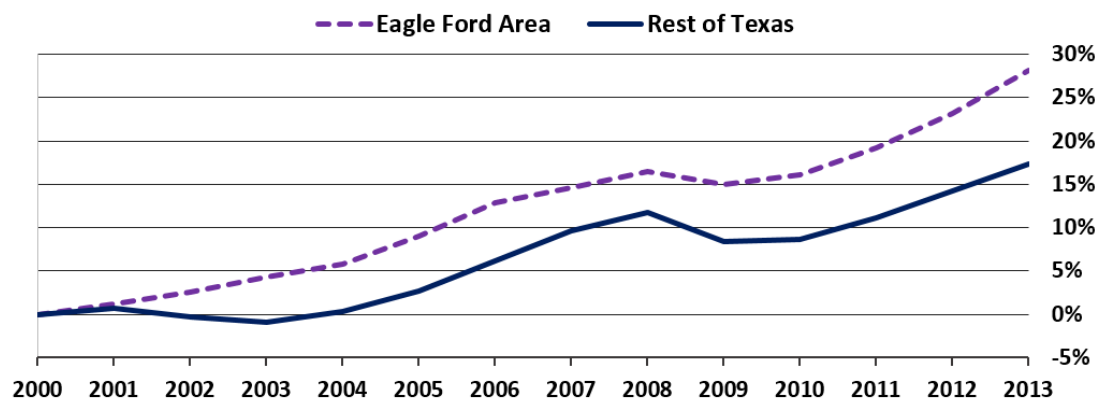


Figure 5.33: Annual comparison of employment growth between the Eagle Ford Shale area and the rest of the state.

The Eagle Ford region witnessed moderate changes in mining employment during the early part of the decade. In fact, prior to 2010, the local mining job growth closely followed the other industries. After 2010, the local mining sector skyrocketed by nearly 100 percent in jobs. This ramp-up corresponds to the spike in oil well completions. The additional mining jobs were concentrated in the primary-tier production counties. These counties experienced approximately 190 percent gains in mining related employment from 2000 through 2013. Meanwhile, the secondary and tertiary-tier production counties showed increases of 74 percent and 79 percent respectively in mining jobs.

The Professional & Business sector showed significant gains in employment throughout the study period. Between 2005 and 2013, the sector expanded by nearly 50 percent. Furthermore, this sector continually experienced growth in employment, even during the financial crisis. In contrast, all of the remaining major sectors showed some level of decline in employment after the 2008 financial crisis. For example, the Construction and Financial Activities sectors did not regain their pre-recession levels of employment until 2013. Meanwhile the Trade, Transport & Utilities sector reached its pre-recession level of employment in 2011 and continued to grow through 2013 (Figure 5.34).

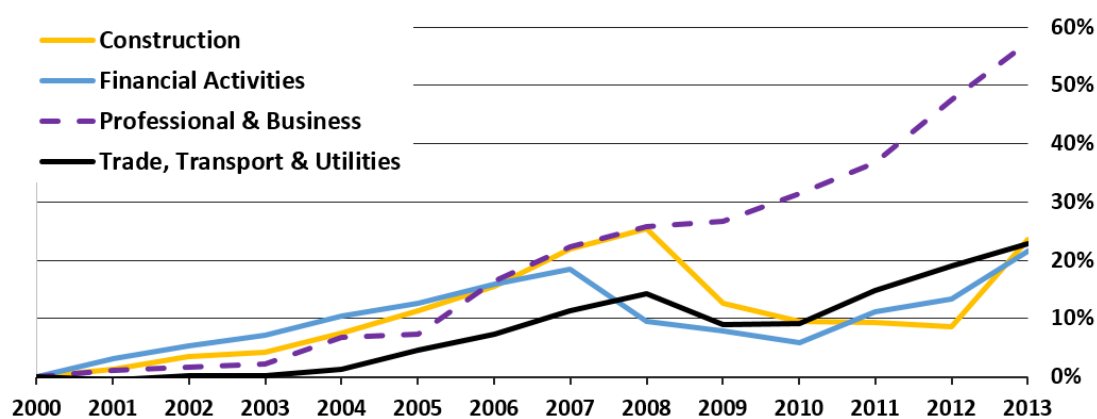


Figure 5.34: Comparison of annual employment growth among the major industries - with the Mining sector excluded - in the Eagle Ford Shale area.

The highest growth period in average local weekly mining wages took place between 2009 and 2012. During the entire timeframe, the Eagle Ford Mining sector experienced the largest gains in average weekly wages out of the five study areas. The Professional & Business sector in the Eagle Ford region witnessed the second largest gain of 83 percent in wages, followed by the Construction sector with a 79 percent increase. Lastly, the Financial Activities along with Trade, Transportation & Utilities sectors displayed similar gains of approximately 68 percent from 2000 to 2013 (Figure 5.35). Comparison in wage growth between the overall regional average and the rest of the state showed a slight negative gap from 2007 to 2010. After 2010, the gap reversed and the Eagle Ford area witnessed a higher rate in wages than the rest of the state.

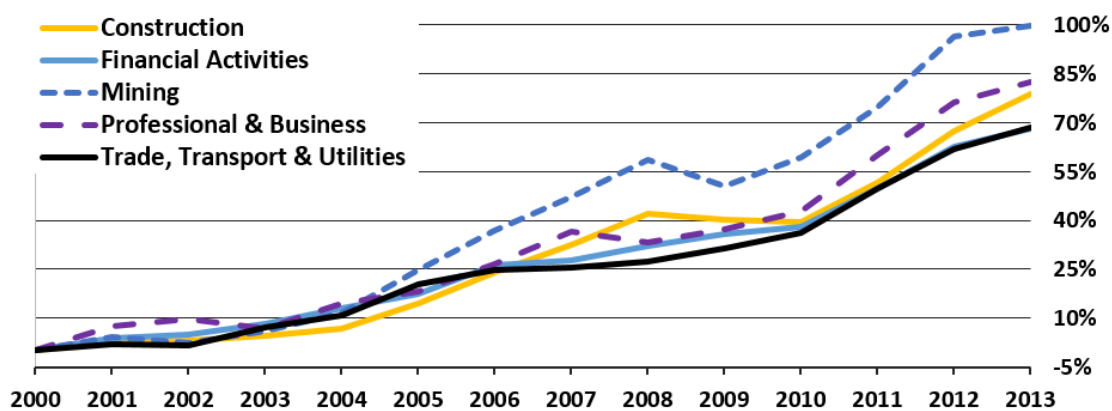


Figure 5.35: Average annual weekly-wage growth by industry in the Eagle Ford area.

Public Revenues and Expenditures in the Eagle Ford Region

Prior to 2007, the region witnessed relatively gradual and consistent increases in gross sales. Starting in 2007, the gross sales rates among the production counties began to quickly diverge. Primary-tier production counties in the area showed the largest changes in sales growth from 2007 until 2012. Meanwhile, gross sales in the secondary and tertiary counties increased more gradually (Figure 5.36). Furthermore, since 2007, gross sales

within the three rural counties (Live Oak, McMullen, and Leon) increased very steeply (Figure 5.37). In 2000 the three rural counties accounted for only five percent of the regional gross sales but by 2013 that share expanded to 16 percent.

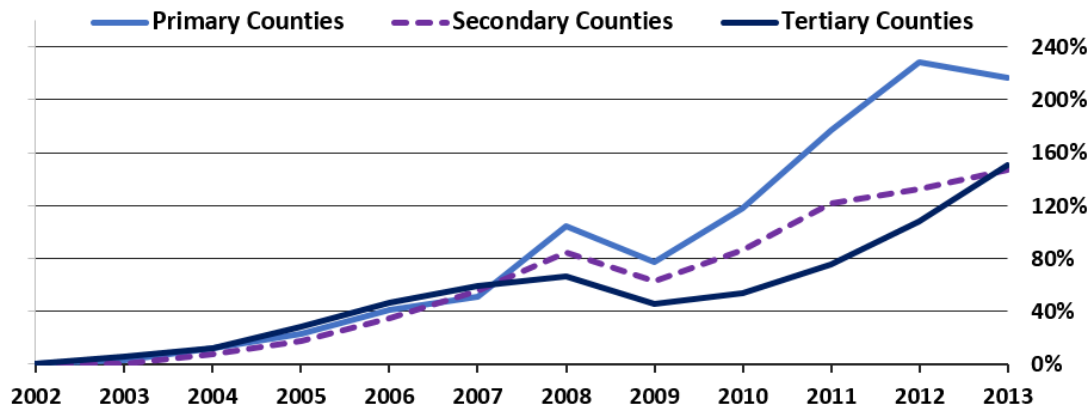


Figure 5.36: Annual gross sales growth comparison between the three production county classification tiers in the Eagle Ford area.

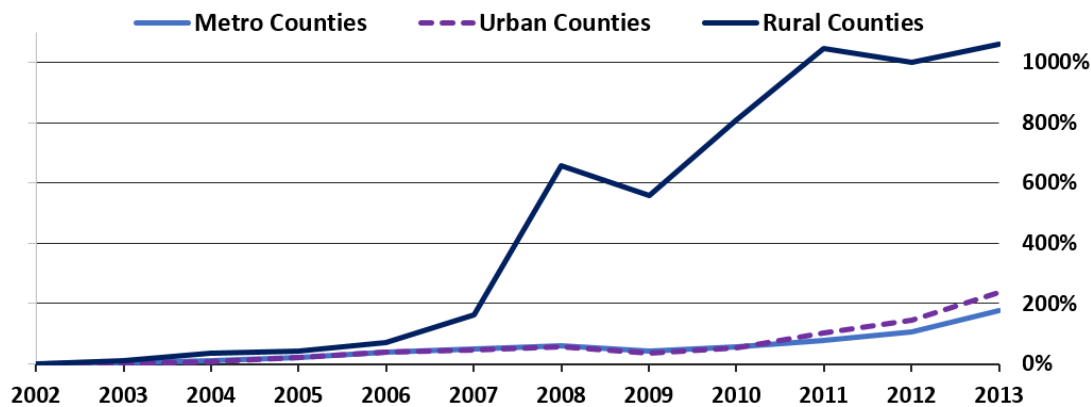


Figure 5.37: Annual gross sales growth comparison in the Eagle Ford area by relative county population.

Among the five production study regions in Texas, the Eagle Ford Shale area showed the highest growth in gross sales during the study timeframe. Initially, the region lagged behind the rest of the state in sales growth before converging with the statewide

average in 2008. Following this convergence, the Eagle Ford area rapidly began to outpace the rest of the state in additional gross sales. Within the latter part of the study period, the positive margin increased by nearly 50 percent. By 2013, the regional gross sales were approximately 170 percent higher than 10 years before. Meanwhile, the rest of the state gross sales data indicated a markedly lower 124 percent increase (Figure 5.38).

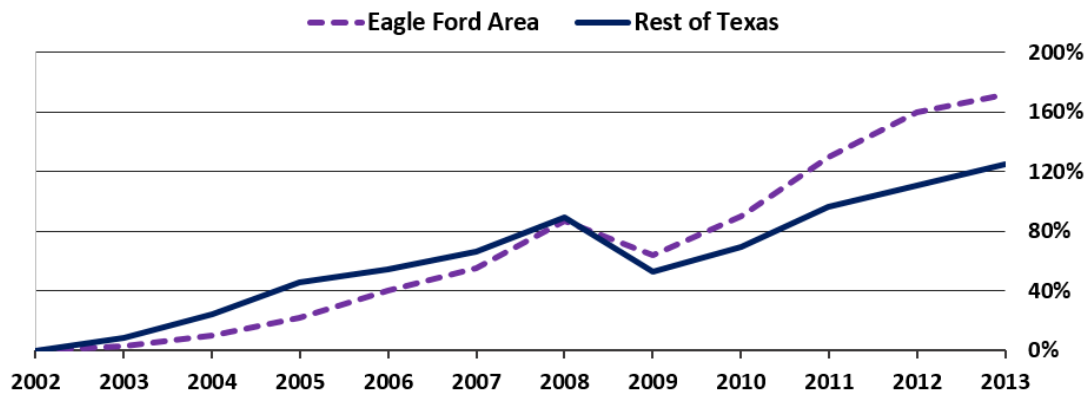


Figure 5.38: Total annual sales growth comparison between the Eagle Ford area and the rest of the state.

As observed in the other study areas, during the period of increased drilling activity, the Mining sector rapidly increased in sales. In the Eagle Ford area, this rapid growth occurred after 2009. By 2013, the overall regional sales in mining increased by 760 percent (Figure 5.39). Wholesale trade showed rapid increases in sales from 2010 to 2012, before stagnating in 2013. The sudden halt in wholesale trade growth is attributed to Gonzales County. The county accounted for 20 percent of total regional wholesale trade in 2012 compared to 14 percent in the following year. This six percent decline does not coincide with a decline in drilling. In fact, the number of completions increased by 70 percent in Gonzales County between 2012 and 2013. Meanwhile, the regional retail sales continued to expand by seven percent between 2012 and 2013 (Figure 5.40).

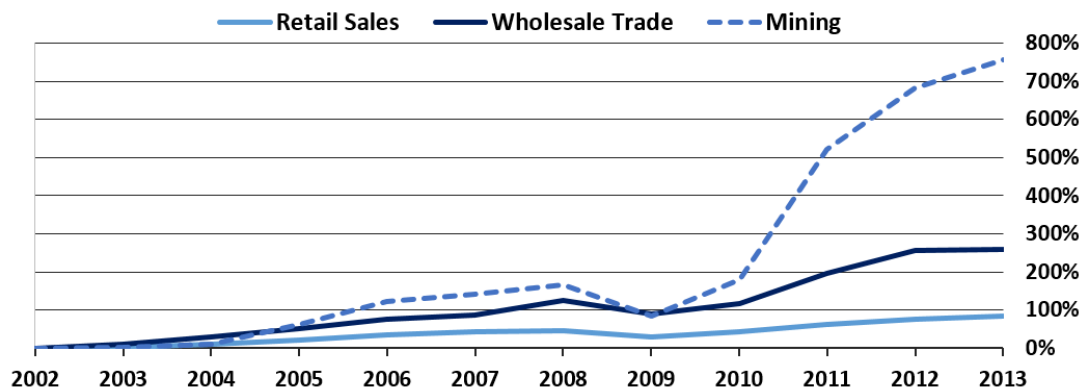


Figure 5.39: Annual sales growth by individual sectors in the Eagle Ford area.



Figure 5.40: Annual retail and wholesale trade growth in the Eagle Ford area.

Hospitality and Traffic Growth Patterns in the Eagle Ford Region

As mentioned in Section 5.1, the Eagle Ford and the Permian Basin regions experienced notable changes in the hospitality sector. There was a sharp increase in the number of hotel room nights-sold within the Eagle Ford area between 2009 and 2013. This steep growth outperformed the statewide average by as much as 67 percent (Figure 5.41). Local hotel revenues closely followed the pattern observed in hotel room nights-sold. Furthermore, eight of the production counties witnessed the number of nights-sold increase

by over 500 percent during the study period. It should also be emphasized that this growth can indirectly impact other local sectors like wholesale trade and construction¹⁴.

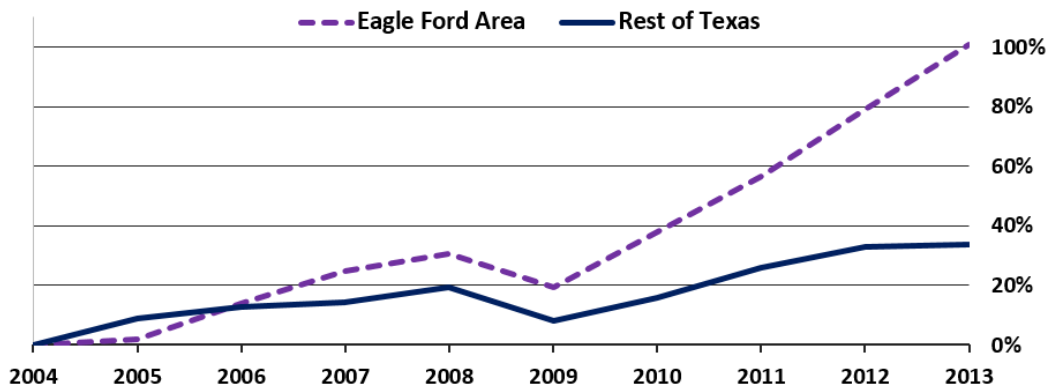


Figure 5.41: Annual comparison of growth in hotel room nights-sold between the Eagle Ford area and the rest of the state.

The recent production boom in South Texas along with the influx of workers has increased overall traffic and traffic related accidents. The inundation of large commercial vehicles into the rural region has spurred some concerns (Hiller, 2012). The impact of rapid population growth in response to the economic developments is evident in the regional traffic accident analysis. Overall, the Eagle Ford area closely followed the annual statewide traffic accident rate until 2007. Subsequently, as the total number of accidents declined until 2010¹⁵, the regional rate began to outpace the rest of the state. By 2013, the growth in traffic accidents in the Eagle Ford area was 12 percent higher than the rest of the state. Among the production counties, the primary-ranked counties witnessed significant increases in traffic related accidents. From 2007 to 2013, the annual traffic accident rate within these eight counties increased by 19 percent (Figure 5.42).

¹⁴ Many of the lodging establishments such as hotels were only recently constructed (in response to the oil boom).

¹⁵ This decline is largely attributed to less driving amongst the public during the 2008-2009 financial crisis.

Additionally, as Miller and Sassan (2014) highlight, the increased truck traffic has taken its toll on the historically low-volume county roads and county road expenditures analysis indicates continued investments in road related expenses in the Eagle Ford area. For instance, spending growth by primary-tier production counties rapidly increased from 2010 to 2013 (Figure 5.43). The largest gains in primary-county road expenditures during this period were seen in LaSalle, DeWitt, and Karnes counties which witnessed 649 percent, 278 percent, and 161 percent increases respectively in county road expenditures.

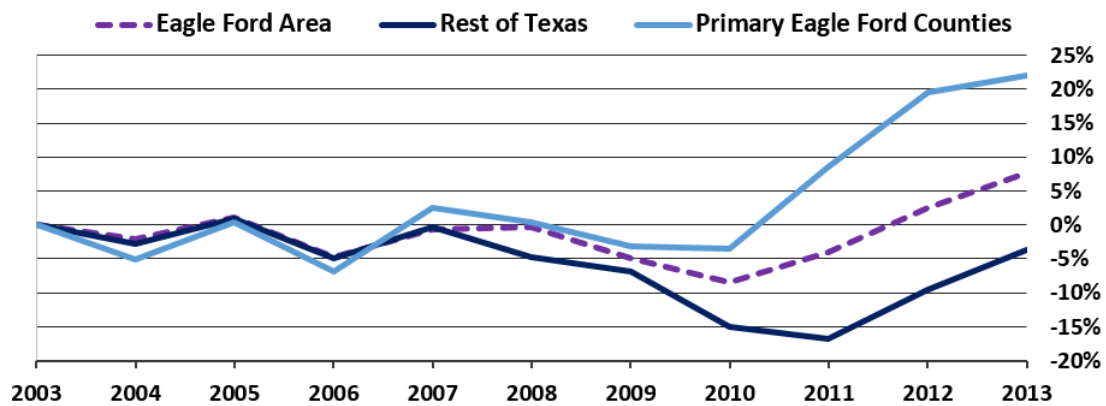


Figure 5.42: Annual traffic accident growth comparison between Eagle Ford counties and the rest of the state.

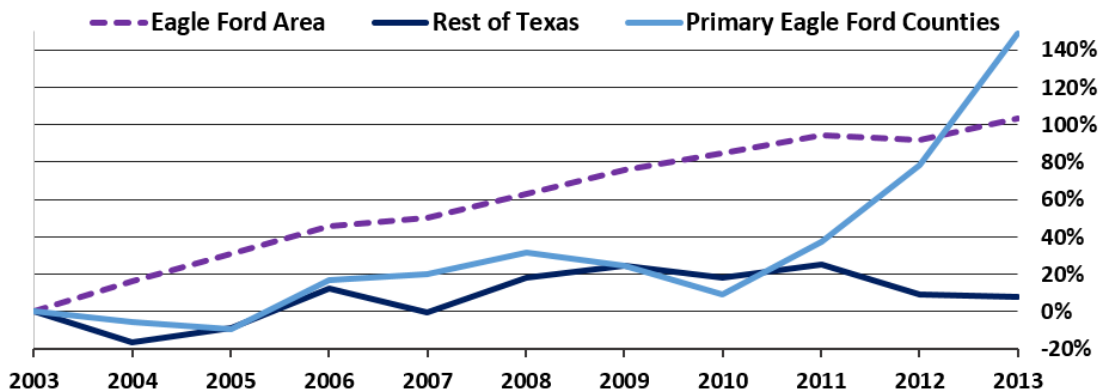


Figure 5.43: Annual county road expenses comparison between Eagle Ford counties and rest of state.

As described in Section 4.1, the success of an individual reservoir depends on multiple factors. For example, proximity to distribution networks and installed infrastructure is an essential factor. Following the recent Eagle Ford boom, large-scale pipeline investment projects have made it easier to transport the extracted hydrocarbons from the wellhead to the distribution network (The Oil Daily, 2011). As Tunstall et al. (2014) indicate, the growing access to the distribution networks has increased the export of gas and greatly reduced the regional flare rate¹⁶. Much of the oil is shipped to the nearby Port of Corpus Christi where it is exported to refineries that can process it. Additionally, major energy companies like Schlumberger, Halliburton, and Weatherford have invested in the construction of new service and business facilities just north of the Eagle Ford area (Gonzalez, 2011; Vaughan, 2012a; Vaughan, 2012b; Vaughan, 2013a). The rapid economic development as a result of increased oil and gas production in South Texas is evident. As described in the above analysis, the counties of this mostly rural region have economically outperformed the rest of the state. However, this sharp growth has sparked concerns about related impacts including, excessive water use (Leclerc, 2014), increased traffic (Hiller, 2012), and road damages (Miller and Sassan, 2014). Further discussion on each of these topics is provided in Chapter 8.

Permian Basin Region – West Texas

The Permian (299 – 251 MA) Basin of West Texas, stretching across the Texas – New Mexico border, is home to some of the largest U.S. oil fields. Major reservoir discoveries in this region date back to the 1920s (Tennyson et al., 2012). Altogether, the area is estimated to hold 747 MMBO of undiscovered technically recoverable oil (Schenk et al., 2007). Additionally, the Permian Basin unconventional resources are estimated at

¹⁶ Excess (‘associated’) natural gas that cannot be captured is commonly flared at the well site through flare stacks.

335 MMBO of proved oil reserves (EIA, 2014f) and 510 MMBO of undiscovered technically recoverable oil (Schenk et al., 2007).

As previously noted, some of the hydrocarbon play-areas that are discussed in this thesis encompass multiple productive sedimentary formations.¹⁷ The Permian Basin is distinct in this regard. Geologically, this sedimentary conglomerate actually consists of two major structural sub-basins: the Delaware Basin to the west and the Midland Basin to the east¹⁸. These two basins are subdivided by the Central Basin Platform. Hence, the depositional environments and depths vary throughout the area (USGS, 1995; Sutton, 2014). Moreover, the area overlies multiple unconventional formations, including the Spraberry formation, the Wolfcamp Shale, and the Woodford formation (Schenk et al., 2007). Attempts to hydraulically fracture some of these tight formations date back to the 1950s (Olien and Hinton, 2007).

Increasing oil prices and the introduction of enhanced extraction techniques have re-awakened rural West Texas. While the conventional legacy wells have been experiencing declines in production, the new wells drilled into the low-permeability formations continue to increase the overall regional output of crude oil. As a result, by 2013, the Permian Basin accounted for 18 percent of the total U.S. oil production (EIA, 2014g). Using the completion based classification method, the Permian Basin study area was subdivided into 11 *primary*, 16 *secondary*, and 12 *tertiary* production counties (Figure 5.44). Additionally, the Permian Basin region was subdivided into 8 metro, 20 urban, and 11 rural counties, based on the RUCC classification scheme.

¹⁷ e.g. the Haynesville Shale underlies the Bossier Shale while the Eagle Ford overlies the Woodbine formation.

¹⁸ Smaller basins such as the Pecos and the Val Verde are located to the south.

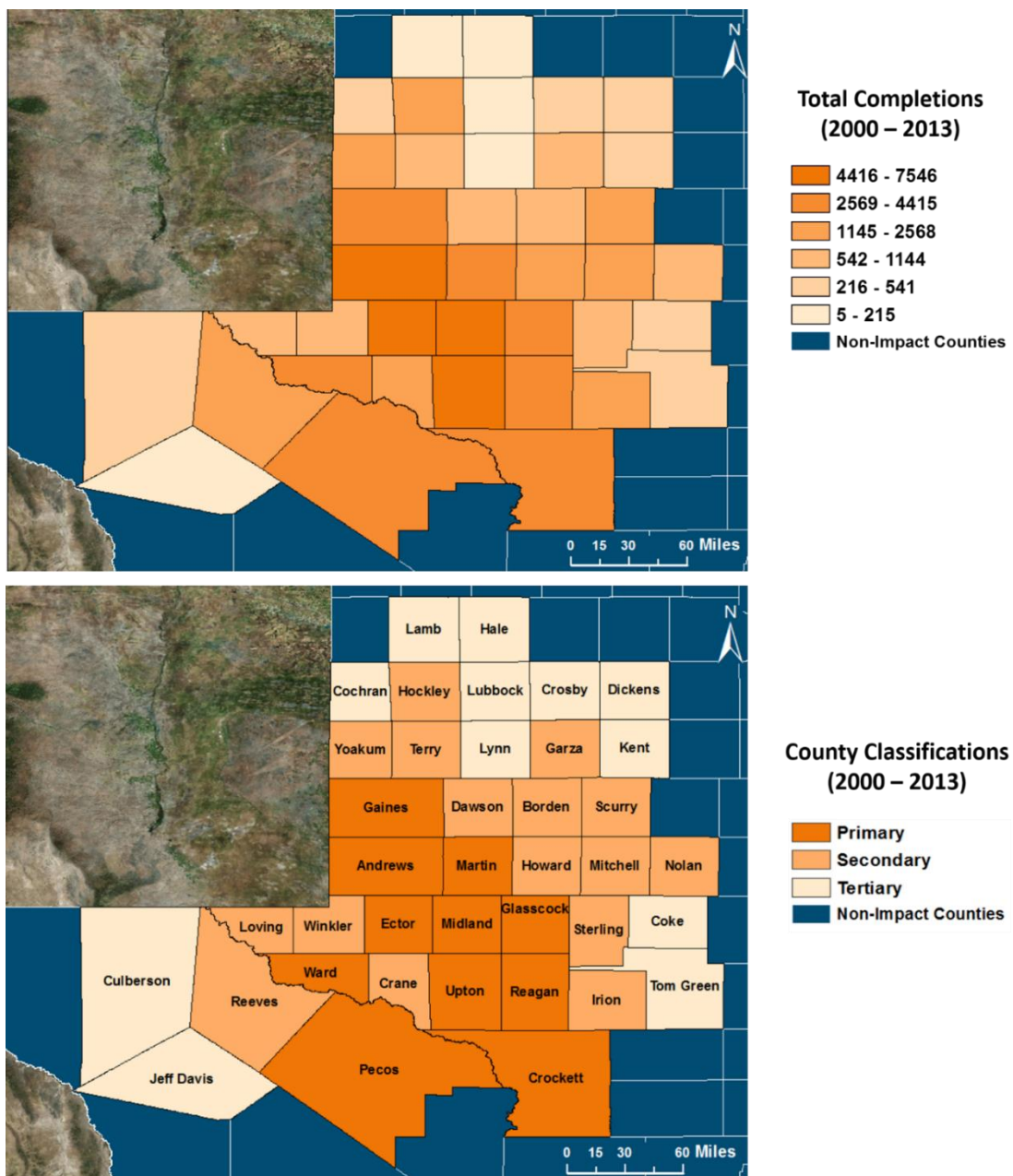


Figure 5.44 Total number of well completions within counties overlying the Permian Basin (a) and respective county classifications between 2000 and 2013 (b).

Throughout the study period, the local production was mostly characterized by vertical wells until 2011. Most of the horizontal wells targeted the tight-oil formations such

as the Spraberry and the Wolfcamp (EIA, 2014e). Hydrocarbon production in this region was focused on crude oil (Figure 5.45) with limited development of the natural gas resources (Figure 5.46).

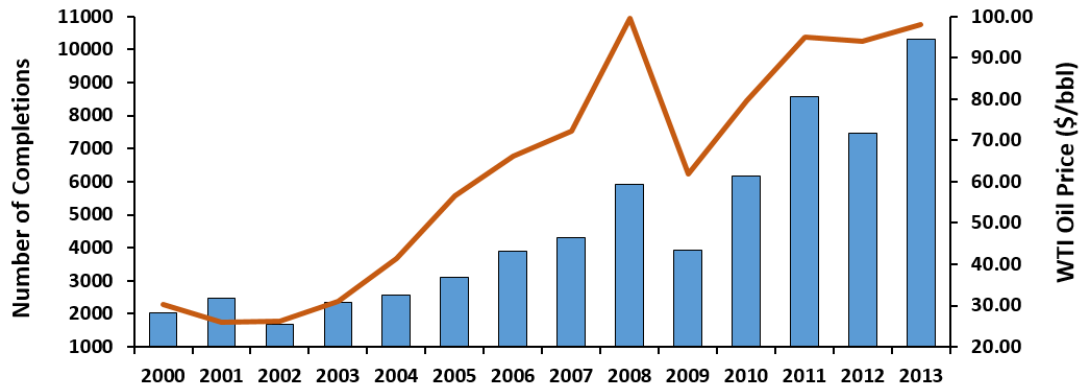


Figure 5.45: Permian Basin oil completions (bars) compared to WTI price of oil (line).

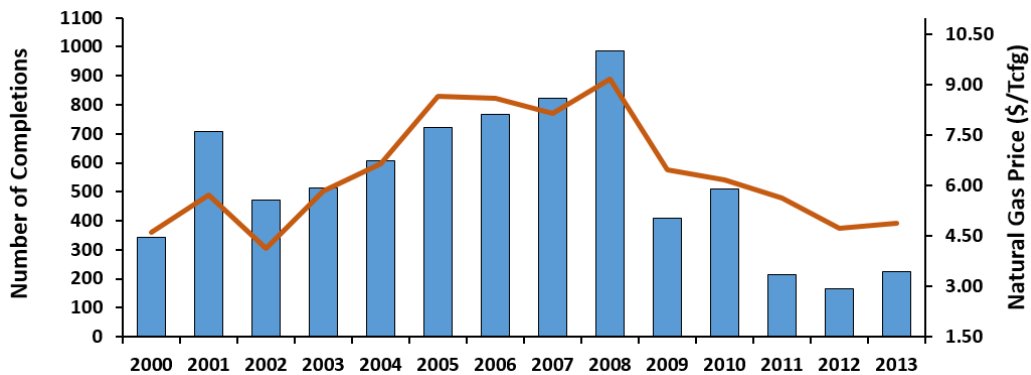


Figure 5.46: Total number of annual gas completions in the Permian Basin area (bars) compared to the respective Citygate price of natural gas (line).

Employment and Wages in the Permian Basin Region

In 2002, the Permian Basin primary-tier production counties began to outpace the rest of the local counties in employment growth. Between 2002 and 2008, employment in the 11 primary-tier counties expanded by 26 percent, followed by a recession driven decline of five percent. After the financial crisis, between 2009 and 2013, the primary-tier

county employment continued to expand by another 26 percent. Meanwhile, the secondary-tier production counties experienced a 12 percent job growth rate during the same post-recession timeframe. Lastly, in comparison to the surrounding area, employment growth in the tertiary-tier counties remained relatively flat. Overall, the tertiary-tier counties gained six percent in jobs for the entire timeframe (Figure 5.47).

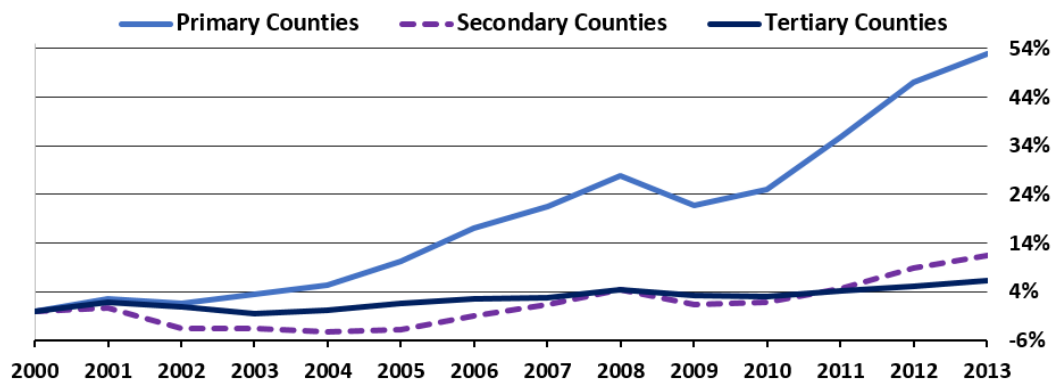


Figure 5.47: Annual employment growth comparison between the three classification tiers of production counties in the Permian Basin area.

The West Texas region is predominantly rural and the local employment growth was most prominent within the few populated counties, especially Midland and Ector Counties. These two counties are home to the two largest regional population centers, Midland and Odessa. In fact, if the two counties were removed from the analysis, then the remaining metro-level counties would indicate a lower employment growth rate than the urban-ranked counties. This is important to consider because the regional workforce may shift from the rural counties to the more populous counties.

After closely following the statewide average from 2000 to 2008, the regional job growth began to deviate from the rest of the state. After 2009, the average employment growth rate in the Permian Basin continuously outpaced the rest of the state counties. This gap between the Permian Basin area employment and the rest of the state increased from

one percent in 2010 to six percent in 2013 (Figure 5.48). This trend coincided with an uptick in new well completions within the region, particularly between 2009 and 2013 when the total number of completions more than doubled and the number of horizontal wellbores increased six-fold. While this rapid growth is notable, it is not as pronounced as that of the Eagle Ford Shale region where employment rose at a steeper rate.

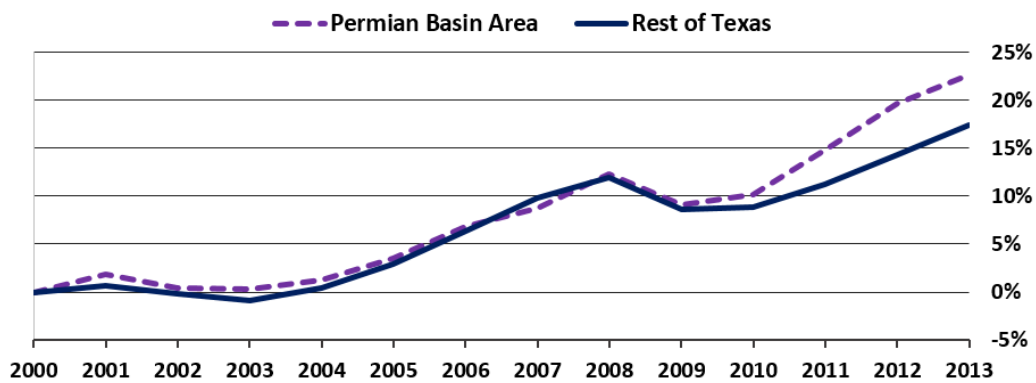


Figure 5.48: Total annual employment growth comparison between the Permian Basin area counties and the rest of the state.

Employment comparison between the major industries in the Permian Basin indicates varying patterns of growth. Throughout the study timeframe, employment in the Mining sector increased by nearly 90 percent. The period of most rapid growth followed the 2008 financial crisis. In the short timeframe between 2009 and 2013, the mining employment increased by approximately 50 percent. This growth is significant, especially when considering that by 2013, nearly 14 percent of the regional workforce was in the mining sector. This is in contrast to the gas-rich Barnett and the Haynesville Shale areas where mining represented a small percentage of the overall jobs.

In addition to the Mining sector, other major industries in the Permian Basin region witnessed rapid growth in employment. Above all, the local Construction sector showed a sharp rebound after the 2008 housing crash. Between 2010 and 2013, the sector increased

by 21 percent in employment. The Permian Basin area experienced the most growth in construction jobs of all the study areas, if the Granite Wash region is excluded.¹⁹ The Trade, Transportation and Utilities sector in the Permian Basin area showed a limited decline during the financial crisis, followed by a steady increase in new jobs from 2010 to 2013. Whereas the Financial Activities sector did not begin expanding again until 2011. The Professional and Business sector showed the steepest drop in jobs during the financial crisis, followed by a rebound in 2010 and stagnant growth since (Figure 5.49).

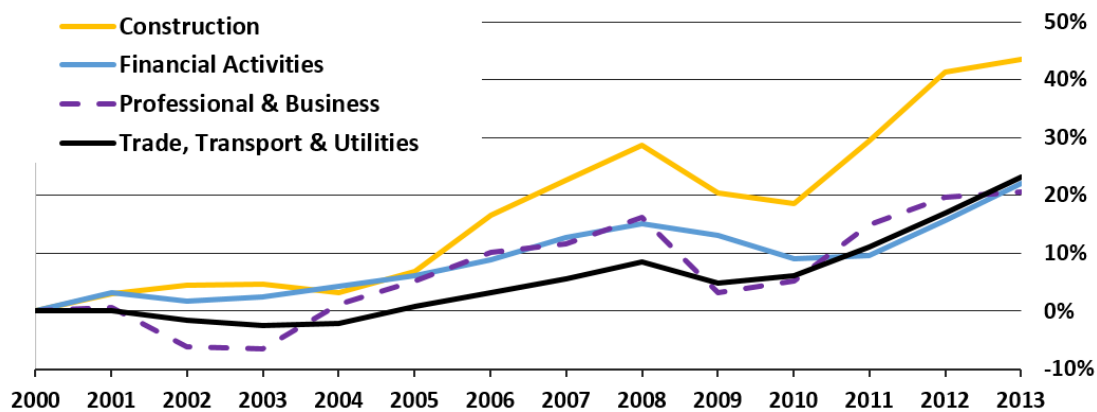


Figure 5.49: Comparison of annual employment growth among the major industries - with the Mining sector excluded - in the Permian Basin area.

Contrasting the trends in the Barnett and the Eagle Ford areas, the highest wage growth in the Permian Basin was observed in the Professional and Business sector rather than the Mining sector. In 2008 the local Professional and Business sector wage growth was 25 percent higher than that of the Mining sector. This gap in wage growth decreased to 17 percent by 2013. Another unique aspect of the Permian Basin average weekly wage trends was observed in the Construction sector. During the 2008-2009 recession, construction wages continued to rise in the Permian Basin area while all the other study

¹⁹ Note that the Granite Wash area represents a very small percentage of construction employment compared to that of the Permian Basin region.

areas witnessed declines in construction wages during the recession. Throughout the study period, the Permian Basin experienced the highest growth in construction wages. The only exception was the Granite Wash area which includes a very small construction workforce. Mining wages represented the second highest growth rate in the West Texas region. During the study timeframe, the pattern in the Permian Basin mining wages closely resembled that of the Eagle Ford area. Additionally, the Trade, Transportation, and Utilities sector showed continued growth in wages with a slight dip during the financial crisis. Finally, the Financial Activities sector wages witnessed the lowest growth rate during the timeframe. The Financial Activities sector also endured the longest stagnation in wages between 2007 and 2010 (Figure 5.50).

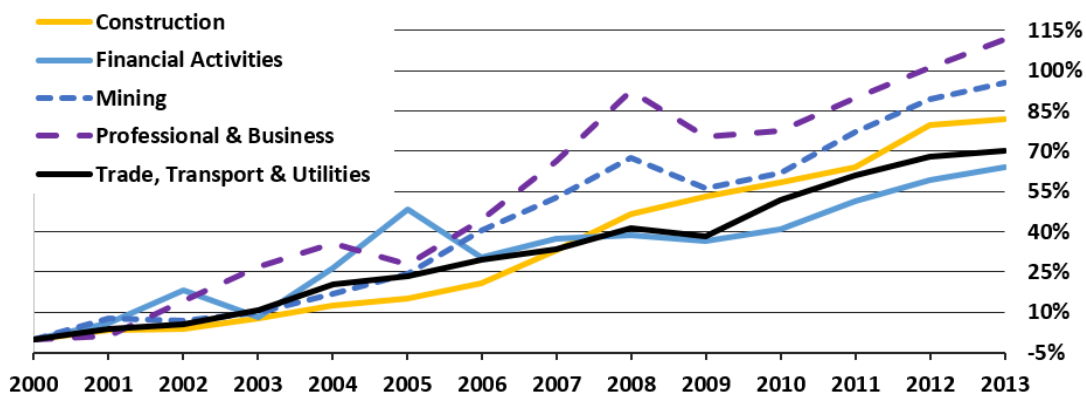


Figure 5.50: Annual comparison of the average weekly wage growth between the major industries in the Permian Basin area.

Similar to the Eagle Ford region, mining wages observed in the Permian Basin area indicate a higher growth rate than the rest of the state, particularly after 2006. In contrast to South Texas, the West Texas mining wages experienced two rapid ramp-ups throughout the study timeframe. The first sharp deviation from the statewide average occurred between

2006 and 2008. The second deviation in mining wages occurred between 2010 and 2013 (Figure 5.51). Both shifts were concurrent with growth in drilling activities.

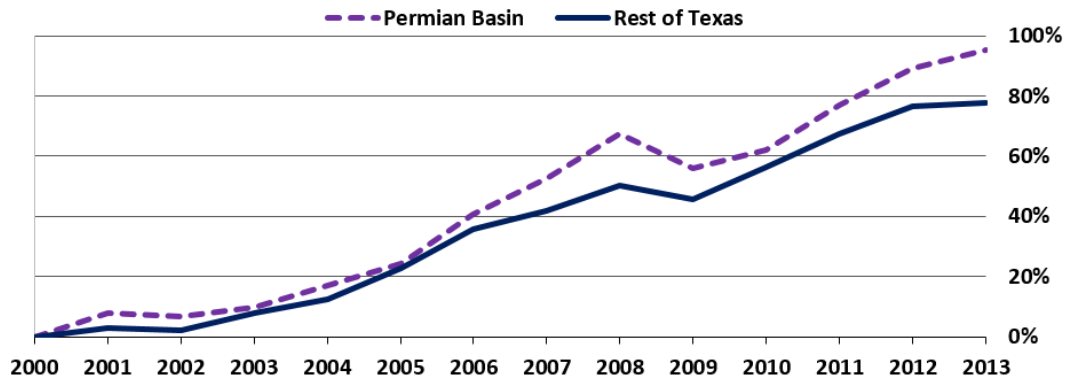


Figure 5.51: Average annual mining sector wage growth comparison between the Permian Basin area and the rest of the state.

Public Revenues and Expenditures in the Permian Basin Region

Sales data analysis of the Permian Basin region indicated that much of the growth was contained in the primary-ranked production counties. These 11 counties accounted for more than 45 percent of the regional sales during the study period while containing only 35 percent of the local population (based on the 2010 U.S. Census estimates). In contrast, the regional tertiary-tier production counties experienced limited growth in gross sales during the study period, trailing behind the statewide gross sales average from 2004 to 2013. The gross sales in secondary-tier production counties oscillated throughout the decade with a sharp decline in sales occurring during the recession from 2008 to 2010. However, from 2011 to 2013, the secondary-tier counties experienced a rebound in gross sales, exceeding the statewide average (Figure 5.52).

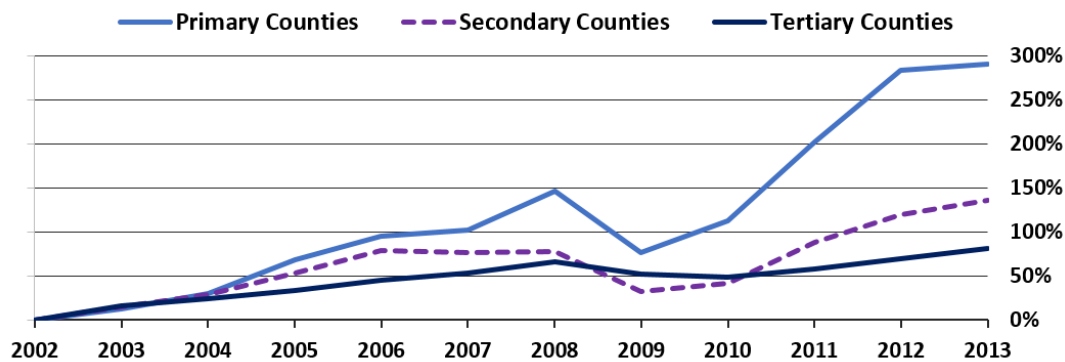


Figure 5.52: Annual gross sales comparison between the three production county classification tiers in the Permian Basin area.

Additionally, the more populated counties in the Permian Basin area showed a higher growth rate in gross sales, especially from 2009 to 2013. Initially, the urban-ranked counties outpaced the rest of the region in sales until 2009 when the metro counties experienced a rapid increase in sales. As mentioned in the employment analysis, Midland and Ector counties greatly influenced the regional economic trends. If the two counties are excluded from the analysis, then the sales of the local metro counties would be notably lower than that of the urban counties. Meanwhile, the rural counties in the Permian Basin showed lower growth in total sales with a sharp decline during the financial crisis.

Altogether, the average county in the Permian Basin area outperformed the rest of the state in total sales growth. In comparison to the rest of the study regions, the Permian Basin witnessed the highest growth in sales until 2009 when sales in the Eagle Ford area began to rapidly increase. The largest positive deviation from the statewide average sales rate occurred between 2010 and 2013. The Permian Basin region showed a 54 percent growth rate in sales during the latter part of the study timeframe. In fact, many of the counties more than doubled in gross sales. These sharp spikes in sales were most prominent in rural counties that have historically witnessed relatively low sales.

The Permian Basin showed the highest sales rates in Mining. The steepest growth rate occurred between 2009 and 2012. During this short period the sector increased by 193 percent in sales. The local Mining sector represented approximately 10 percent of the local sales during the study timeframe. This is distinctly different than the trends observed within the more populated regions like the Barnett area where sales in the Mining sector were surpassed by other major industries. Additionally, among the five study areas, growth rates in the Permian Basin wholesale trade were most closely aligned with the growth observed in retail trade (Figure 5.53). The growth in Permian Basin retail sales exceeded the state average while the wholesale trade sales rate was lower than the statewide average.

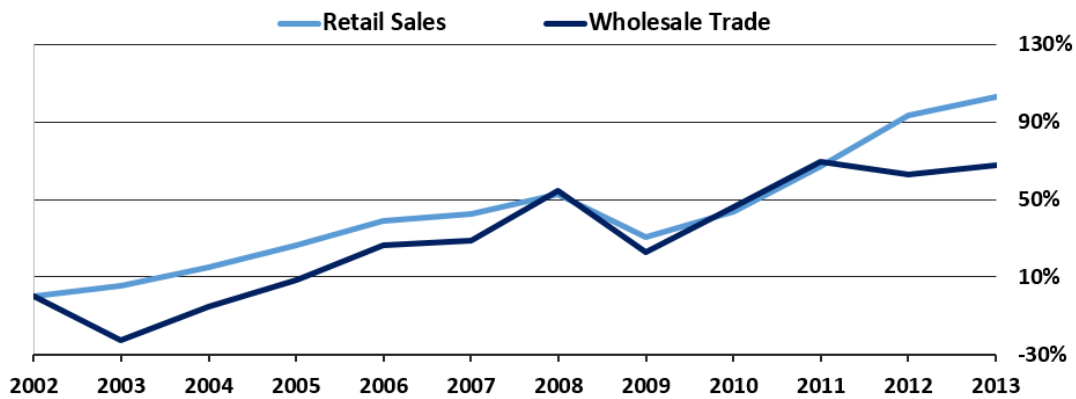


Figure 5.53: Annual comparison of the sales growth between retail and wholesale trade in the Permian Basin area.

Hospitality and Traffic Growth Patterns in the Permian Basin Region

Hospitality related economic growth was most pronounced in the Permian Basin as compared to the other hydrocarbon producing regions in Texas. Hospitality establishments in the Permian Basin area witnessed a 98 percent increase in hotel room nights-sold during the entire study timeframe. The steepest growth rate occurred between 2010 and 2012 during which the number of hotel room nights-sold nearly doubled (Figure 5.54). Hotel revenue growth closely followed this increasing trend. Throughout the analysis period, the

Permian Basin exceeded the statewide average in hospitality sector growth by a significant margin. The only area that experienced a similar growth rate was South Texas.

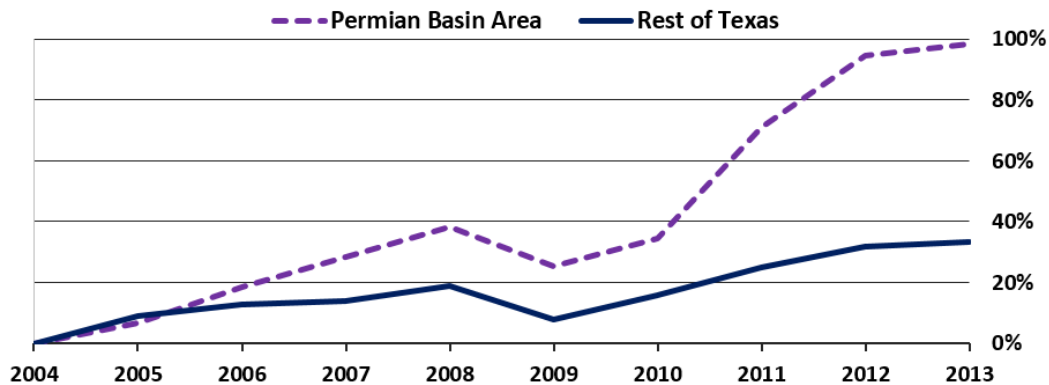


Figure 5.54: Annual comparison of the growth in hotel room nights-sold between the Permian Basin area and the rest of the state.

The Permian Basin traffic accident analysis patterns indicated two crests occurring during the study period, particularly within the more active production counties. These two upticks in traffic accidents slightly lag the two pre and post-recession production booms (Figure 5.55). Traffic accident analysis of the tertiary-tier production counties in the Permian Basin indicates a contrasting trend to that of the primary and secondary-tier production counties. For instance, both, the primary-tier and the secondary-tier counties showed a spike in traffic accidents in 2007, followed by a steady decline during the financial crisis. Whereas, the tertiary-tier counties witnessed a limited increase in accidents during the boom, followed by a brief spike in traffic accidents during the recession. This pattern is consistent with the hypothesis that labor moves from the rural to urban and metro counties during booms and may return during the subsequent slowdown.

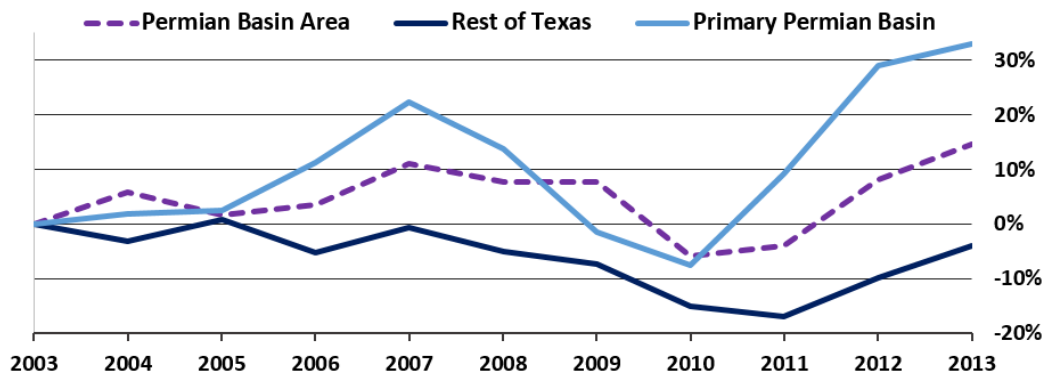


Figure 5.55: Traffic accident comparison between the Permian Basin, the primary production counties in the Permian Basin, and the rest of the state.

The Permian Basin witnessed higher rates in accidents than the rest of the state perhaps due to increased traffic. Consistent with this pattern, the region also allocated more funding year-over-year towards road repairs. Growth in local road expenditures is somewhat parallel to the Eagle Ford area. The average local county spent a notably higher year-over-year amount on road repairs than the average statewide county. This is most evident in the primary-ranked production counties which witnessed continued growth in county road expenditures, even during the financial crisis (Figure 5.56).

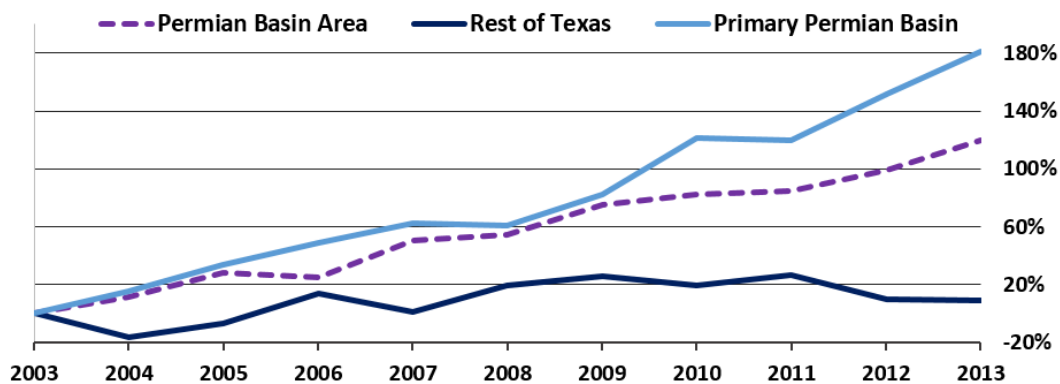


Figure 5.56: County road expenses comparison between the Permian Basin counties, the primary production counties in the Permian Basin, and rest of state.

The Permian Basin has been referred to as the nation's most prolific oil play in recent years (EIA, 2014g). The surge in Permian Basin oil production has exceeded the production level of the federal blocks in the Gulf of Mexico. Equally important is that much of this growth is attributed to the unconventional sedimentary formations like Spraberry and Wolfcamp (EIA, 2014g). As highlighted in the previous analyses, the effects of these rapid developments are notable in the local labor and business markets. For instance, the labor shortages occurring in West Texas (Gilmer and Thompson III, 2012) have increased the local wages as evident in the average weekly wage analysis. Additionally, as emphasized by Gilmer and Thompson III (2012), the Permian Basin holds an advantage over the other hydrocarbon plays due to its existing infrastructure from previous oil booms. Ultimately, as history has shown (MacCormack, 2012), the growth in West Texas is closely tied to the global oil market. Thus, this recent growth must be carefully evaluated with respect to future oil price projections as discussed in Chapter 7.

Granite Wash Region – The Texas Panhandle

Tucked away in the eastern corner of the Panhandle, spanning across the Texas – Oklahoma border is the Granite Wash. The Pennsylvanian (299 – 323 MA) Granite Wash formation of the Anadarko Basin Province is estimated to hold 809 BCF of undiscovered gas and 16 MMBO of oil resources (Higley et al., 2011). There are only five designated study counties for the Granite Wash region: Hemphill, Lipscomb, Ochiltree, Roberts, and Wheeler. The local population is the most rural of all the study regions. In fact, the combined population of the designated study counties was estimated to be less than 24,000 people in the 2010 Census. As a result, the economic analysis is less comprehensive in this section because much of the economic data was incomplete. Instead, a more general overview is presented to provide some measure of the regional economic growth.

E&P developments in this region were primarily characterized by conventional drilling until 2008 when a spike in horizontal well completions occurred (Figure 5.57). In particular, the local drilling operations focused on natural gas resources (Figure 5.58). After 2008, the number of annual natural gas completions leveled off and remained flat through 2013 as a consequence of the gas price crash.

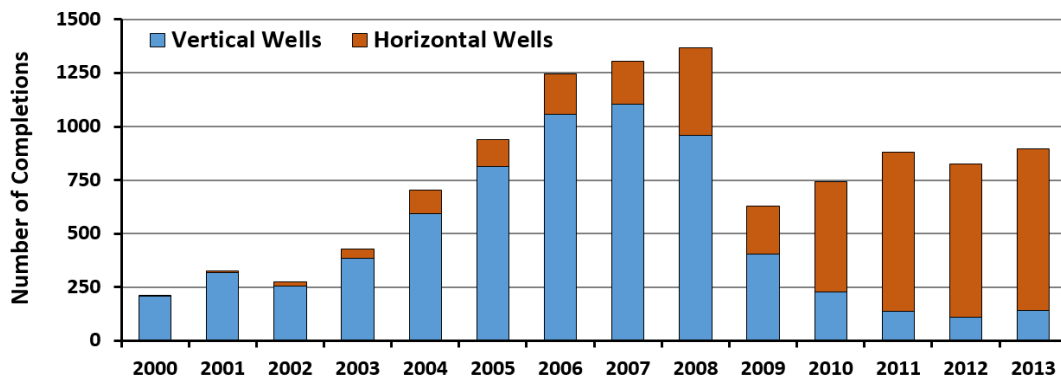


Figure 5.57: Annual comparison between the number of vertical and horizontal well completions within the Granite Wash area.

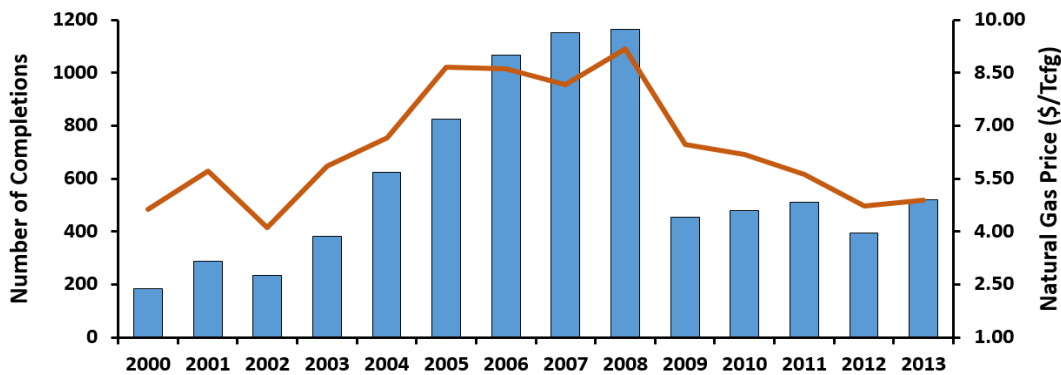


Figure 5.58: Total number of annual gas completions in the Granite Wash area (bars) compared to the respective Citygate price of natural gas (line).

In the latter part of the last decade, operators began increasing the share of oil-targeted completions. This increase in oil completions was contemporaneous with the

climbing price of crude oil (Figure 5.59). While the new oil-focused completions added to the overall growth in development, this growth was not nearly as steep as that observed in the early part of the decade with natural gas development.

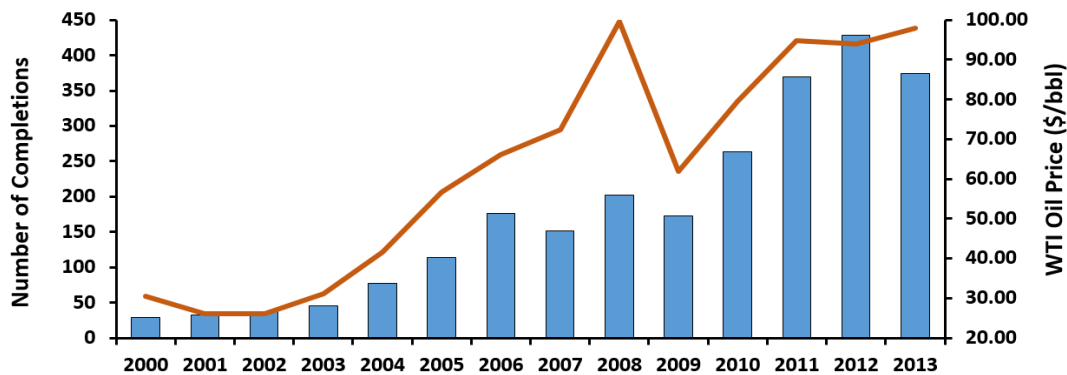


Figure 5.59: Total number of annual oil completions in the Granite Wash area (bars) compared to the respective WTI price of oil (line).

Beginning in 2002, the job growth rate in the Granite Wash began to exceed the statewide average by a significant margin. This difference is due to the small absolute level of the population at the beginning of the study and the influence of the local Mining sector. Mining represented 26 percent of the combined local workforce during the study period. Additionally, the average weekly wages in the region closely followed shifts in Mining. From 2000 to 2008, the local average wages nearly doubled, before retracting by 17 percent in 2009. Wages followed the job trend and increased to pre-recession levels by 2012.

The pattern observed in the employment and wage analysis is also reflected in the local wholesale trade throughout the study timeframe. Wholesale trade rapidly ramped up from 2005 to 2008 and again from 2009 to 2011. Whereas, retail trade witnessed three peaks in sales during the same time period (Figure 5.60). Regional sales were exceptionally volatile in comparison to the rest of the state. For instance, gross sales between 2006 and 2008 quadrupled before declining by 50 percent between 2008 and 2009 and local gross

sales have remained below the pre-recession level. However, the sales are relatively high when compared to the low sales numbers observed in the region in the early part of the last decade.



Figure 5.60: Comparison between wholesale and retail trade in the Granite Wash counties.

Hospitality data was only available for three counties in the Granite Wash region (Ochiltree, Hemphill, and Wheeler) which limited the analysis. These counties witnessed modest growth in hotel room-nights sold from 2004 to 2008, followed by a decline and then a steep uptick between 2009 and 2012. This uptick coincided with the increase in oil-targeted drilling activities. The local traffic accident analysis indicated two spikes occurring in 2007 and 2012. These two deviations are separated by a five year trough in traffic accident numbers that bottomed out in 2009. Meanwhile, the county road expenditures data showed significant variation year-to-year with a sharp 2011 spike in expenses that can be attributed to Wheeler County. Overall, the Granite Wash region witnessed rapidly fluctuating economic trends across most sectors. Unlike the more populous regions of the state, this predominantly rural area has experienced limited economic activity in the past and the recent shifts in the Mining sector have had a large impact on the local economy.

Statewide County Comparison and Statistical Assessment

The objective of the previous five sections was to illustrate how economic conditions vary among different hydrocarbon formations and the individual counties that overlay those formations. However, a broader supplemental analysis is required in order to capture and compare the differences between counties that are actively engaged in hydrocarbon extraction verses those that are not. This section provides just such an analysis for all the counties in the state of Texas.

A general comparison of economic patterns is provided in Figures 5.61 through 5.65. Aside from gross sales, all the major economic factors indicate higher growth rates in counties with oil and gas production. By 2013, the primary production counties exceeded their neighboring production counterparts by four percent in employment and 10 percent in wage growth. Annual employment growth observed in oil and gas production counties was strongly influenced by the rural counties overlying the Eagle Ford, Permian Basin, and Granite Wash formations. These would be considered the ‘oil and gas boom’ regions of the state. Conversely, the Haynesville Shale²⁰ area has witnessed a reduction in employment and wages in the latter part of the study timeframe. This decreases the overall job growth in the designated production counties by slightly more than one percent. Markedly, the most prominent division between production and non-production counties was witnessed in the hotel revenue growth analysis. By 2013, the designated rural production counties witnessed nearly twice the rate of growth in hospitality revenues. This clearly implies a resource boom.

²⁰ Initially, the prospects of developing the Haynesville Shale brought much optimistic anticipation (Bogan, 2009). However, the continued downward pressure on natural gas prices and the high costs required to develop the play have dampened those prospects.

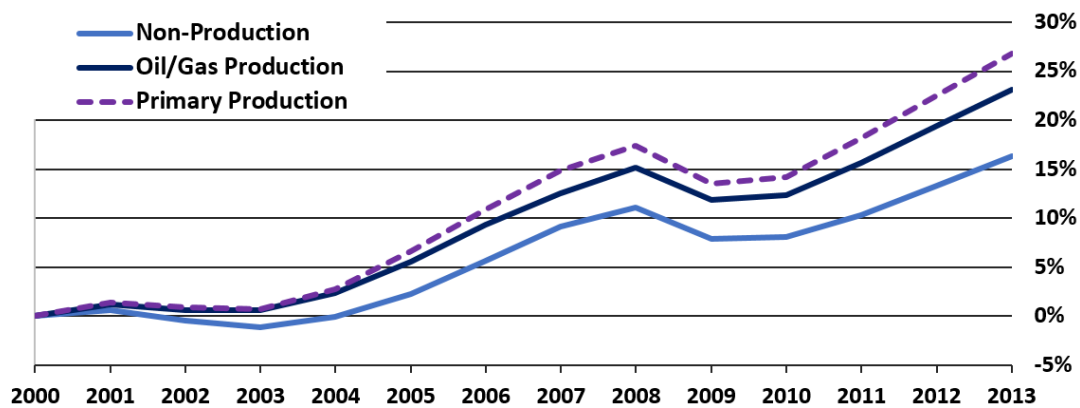


Figure 5.61: Total annual employment growth rates between primary oil/gas production counties, all production counties, and counties with limited or no production.

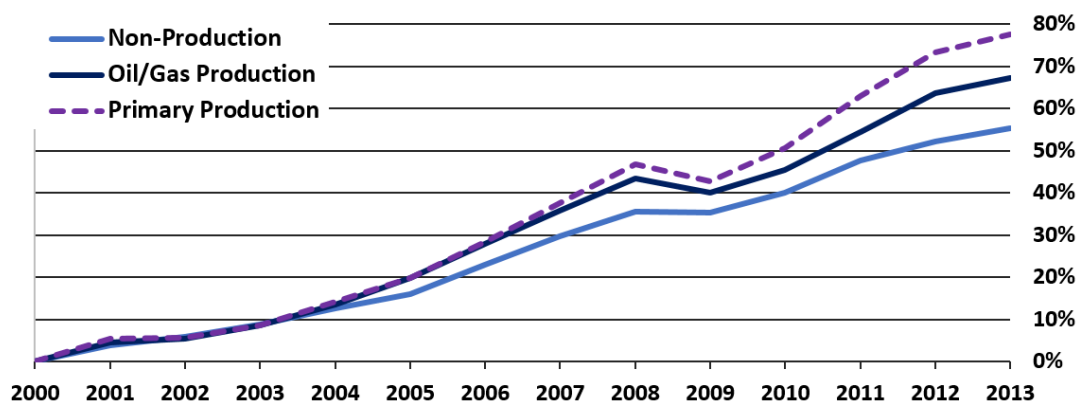


Figure 5.62: Average annual weekly-wage growth rates between primary production counties, all production counties, and counties with limited or no production.

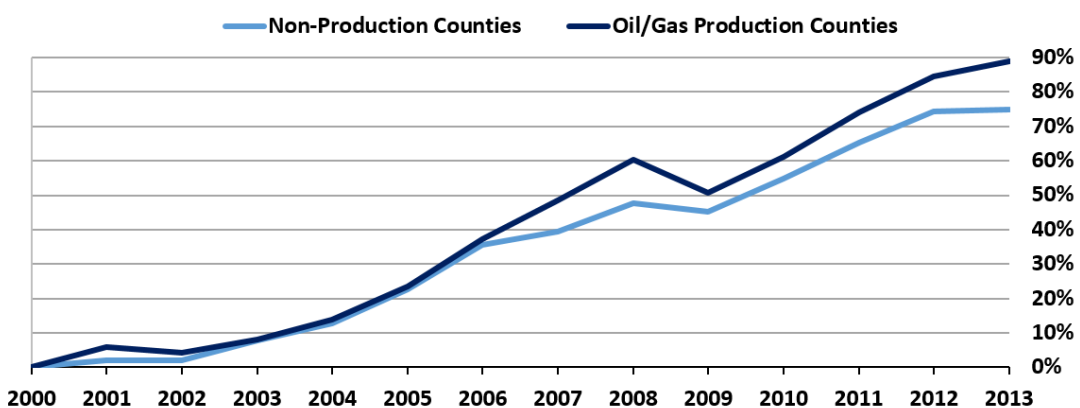


Figure 5.63: Mining only weekly-wage growth rates between oil/gas production counties and counties with limited or no production.

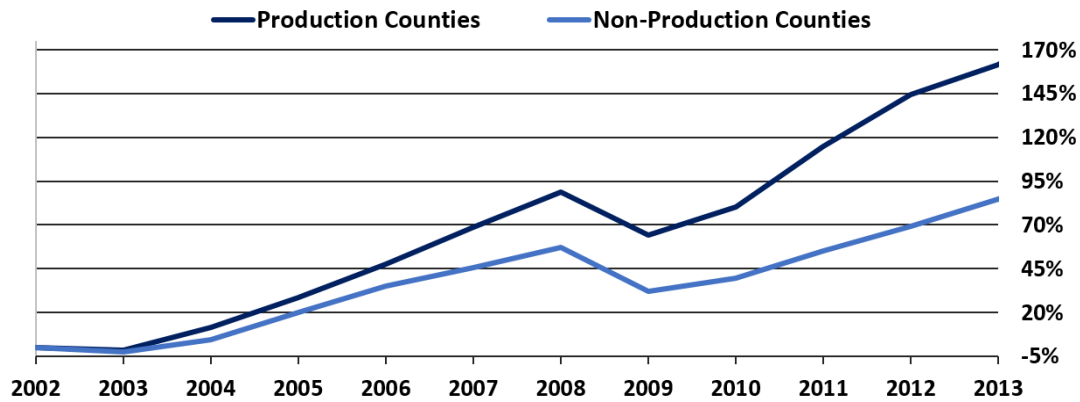


Figure 5.64: Annual hotel revenue growth rates between oil/gas production counties and counties with limited or no production.

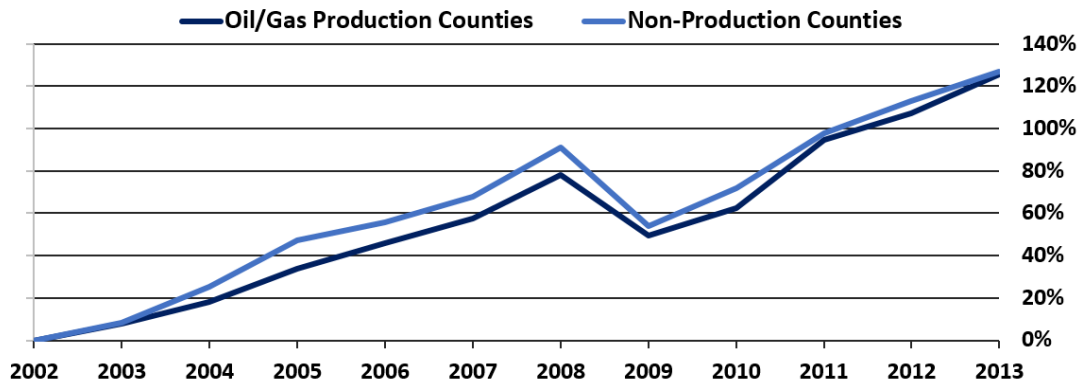


Figure 5.65: Annual gross sales growth rates between oil/gas production counties and counties with limited or no production.

In the final analysis, a series of regressions was performed to quantify the effect of the recent upstream developments on the economies of the designated impact counties. A panel fixed-effects model was applied in this analysis. This type of regression model estimates the marginal effect of oil and gas development on the dependent variables, controlling for unobserved spatial and inter-temporal heterogeneity. A panel dataset was organized using county-year data for the number of horizontal wells, employment, wages, hotel revenues, and gross sales within the counties. For each regression, the number of

horizontal wells was used to predict the economic factors. The number of horizontal wells, rather than vertical or total wells, was chosen as the explanatory variable because this form of drilling is closely aligned with the recent unconventional resource boom. A statistical summary of the individual variables is included in Table 5.1. The general form of each fixed-effect equation is as follows:

$$E_{it} = \beta_1 * horizontal\ wells_{it} + \alpha_i + \alpha_t + e_{it}$$

Where:

E_{it} = economic (dependent) variable in county i , in year t

$horizontal\ wells_{it}$ = number of unconventional wells in county i , in year t

α_i = county fixed effects

α_t = year fixed effects

e_{it} = the error term

Dataset	Variables	Min	Mean	Max	Obs.
Statewide Counties	Horizontal Wells	0	23	1,123	3,048
	Total Employment	26	39,017	2,181,891	3,048
	Avg. Weekly Wages	326	626	1,945	3,048
	Hotel Revenues	22	29,332	1,626,487	2,590
	Gross Sales	16,887	4,962,482,840	533,797,321,959	3,046
Impact Counties	Horizontal Wells	0	49	1,123	1,200
	Total Employment	26	20,234	806,676	1,200
	Avg. Weekly Wages	326	638	1,242	1,200
	Hotel Revenues	104	14,049	674,083	1,008
	Gross Sales	16,887	2,099,920,799	89,887,919,787	1,198

Table 5.1: Statistical summary of the data used in the fixed-effects model. Note, hotel revenue values represent thousands (\$ '000).

The regression analysis focused on the drilling and completion stages instead of the production process because the production process is much less labor intensive. Results from the regression analysis (Table 5.2) suggest a strong positive influence of unconventional (horizontal) well completions on employment in the 100 designated impact counties. The model estimated an increase of 9.01 jobs for every additional horizontal well

in the designated impact counties. Despite the statistically significant positive effect on employment, the small coefficient of horizontal wells (0.09) with respect to wages suggests the effect on average county salaries is not of practical significance. The findings of the model are somewhat analogous to those of Weber (2014) whose model estimated an increase of 18.5 jobs and a mere increase of \$30 per job per year for every BCFG during the recent shale gas boom. Additionally, as was evident in Figure 5.64, revenues in the hospitality sector have surged in the production counties. The rapid growth stems from a sharp influx of labor and a shortage of accommodations and was captured in the regression analysis. The model estimated that for each additional horizontal well in an impact county, an estimated \$41,520 in revenue was attained by the hospitality sector. Lastly, the model indicates that for each additional horizontal well, the impact counties witnessed an increase of \$ 2,641,338 in gross sales (Table 5.2).

Impact Counties				
	Employment	Weekly Wages	Hotel Revenues	Gross Sales
Horizontal Wells	9.01*** (1.41)	0.09*** (0.02)	41.52*** (4.45)	2641338*** (480800)
County Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
R-Squared	0.10	0.39	0.18	0.09
N	1,200	1,200	1,008	1,198
Statewide Counties				
	Employment	Weekly Wages	Hotel Revenues	Gross Sales
Horizontal Wells	5.23 (2.87)	0.12*** (0.02)	32.24*** (8.05)	268405 (2378624)
County Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
R-Squared	0.001	0.29	0.01	0.002
N	3,048	3,048	2,590	3,046

Table 5.2: Effect of horizontal wells on county employment, wages, hotel revenues, and gross sales for *impact*, and *all* state counties. Note, hotel revenue values represent thousands (\$ '000). Standard errors are reported in parenthesis. *** indicates significance at the 99% level, respectively.

Chapter 6. Trends along the Texas Gulf Coast Region

In addition to direct economic impacts from drilling and production operations in the producing regions, these upstream developments can also indirectly affect the downstream refining and maritime shipping operations. For instance, growing local oil and gas production has revived some of the smaller marginal refineries located inland in areas like South Texas (Hiller, 2013; Vaughan, 2013b; Hays and Driver, 2014). The economic growth of inland counties (including the downstream sector) was captured in the previous chapter. Instead, this chapter specifically considers counties that do not overlay any major hydrocarbon formations, but do contain extensive downstream capacity. Particularly, this chapter evaluates the recent trends observed in the large industrial refining and shipping complexes stretched along the Gulf Coast (Figure 6.1).

The Texas coastline is home to some of the largest downstream refining and shipping centers in the U.S. (EIA, 2014a, USDOT, 2014). In fact, the first and the second largest refineries in the nation are located in Jefferson and Harris counties. Combined, the coastal refineries account for approximately 87 percent of the state's total refining capacity (Texas Office of the Governor, 2005). These large refining and petrochemical hubs are collocated with extensive shipping waterways by which crude feedstocks are imported and finished products are exported on a daily basis. Nearby upstream development can influence the downstream operations. Therefore, an overview analysis is provided of the recent trends observed in the downstream sectors of the state that are impacted by increased oil and gas production.

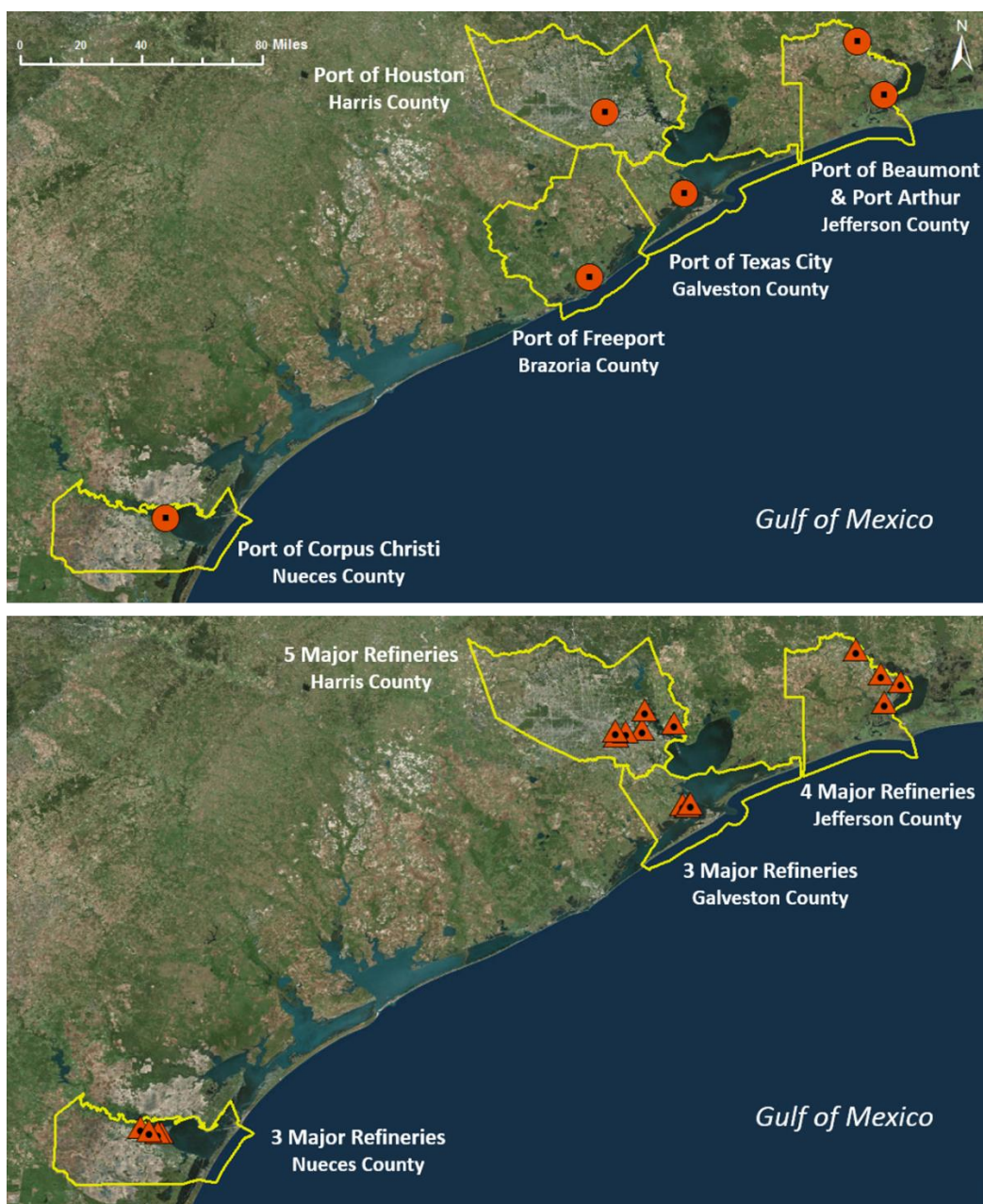


Figure 6.1: Locations of major petroleum shipping hubs (circles) with their respective counties outlined (a) and locations of major petroleum refining/petrochemical complexes (triangles) with their respective counties outlined (b).²¹

²¹ Map compiled based on data from the EIA and the U.S. Army Corps of Engineers.

Over the study timeframe foreign imports at the six largest Texas ports decreased by more than 30 percent (Figure 6.2) while foreign-bound petroleum product exports increased by over 300 percent (Figure 6.3). The sharp decline of foreign imports can be attributed to the replacement of imported conventional light sweet crudes by domestic unconventional light sweet crudes (Kever 2013; EIA, 2015).

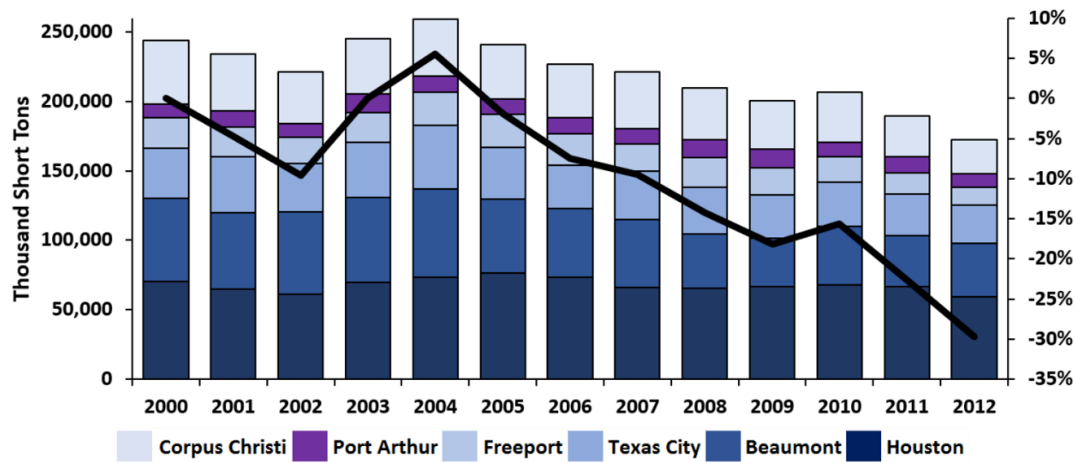


Figure 6.2: Annual foreign inbound petroleum crude shipments by port (bars) and respective average growth rate (line).

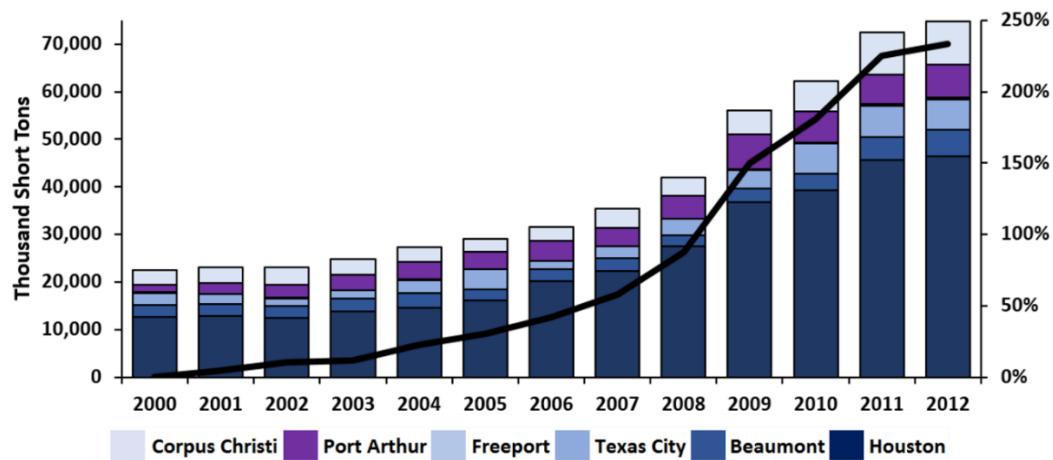


Figure 6.3: Annual foreign outbound petroleum crude shipments by port (bars) and respective average growth rate (line).

The lower priced domestic crude²² is more attractive as it directly benefits domestic refiners whose profit margins increase with lower feedstock prices. However, this development can present various challenges for shipping ports that must accommodate the increased domestic supply. According to a recent report by Platts (2013), production from the Eagle Ford Shale has created a bottleneck in coastal hubs like Corpus Christi where refineries lack the operating capacity to process all the available light sweet crude. Consequently, companies have pursued expanding the port infrastructure in order to export the excess petroleum to other Gulf Coast and East Coast refineries (Platts, 2013). This development is exhibited in the port-trade analysis which indicates that oil imports at the Port of Corpus Christi declined by 42 percent while exports rose by 24 percent since 2000. Additionally, the stockpiling of Eagle Ford supplies has increased the demand for and construction of additional storage capacity along the Corpus Christi refining corridor.²³

During the study period, foreign crude imports decreased while foreign exports increased, whereas, domestic imports and exports both increased. Annual domestic crude imports have increased by 88 percent between 2000 and 2012 while domestic exports increased by 19 percent (Figures 6.4 and 6.5). Domestic petroleum imports and exports witnessed a sharp increase in volume between 2005 and 2007, followed by a steep drop in 2007 and a steady recovery after 2008. Combined, the Texas waterborne crude trade fluctuated during the study period with the latest decline occurring between 2010 and 2012 (Figure 6.6).

²² From 2011 to 2015, domestic WTI Crude was continuously priced at a discount to other price benchmarks like the North Sea Brent Crude. This is largely the result of rapid growth in U.S. production and limited exports because of the 1970s crude oil export ban.

²³ Based on personal observation of extensive storage infrastructure construction.

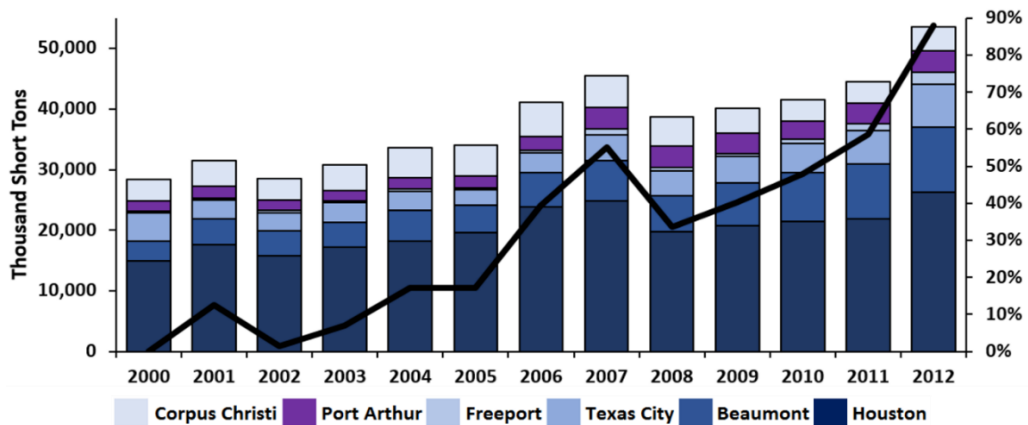


Figure 6.4: Annual domestic inbound petroleum crude shipments by port (bars) and respective average growth rate (line).

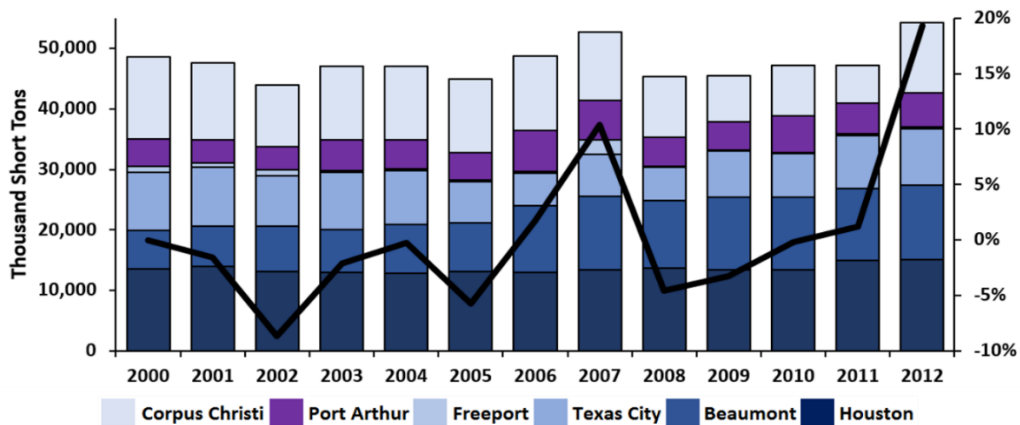


Figure 6.5: Annual domestic outbound petroleum crude shipments by port (bars) and respective average growth rate (line).

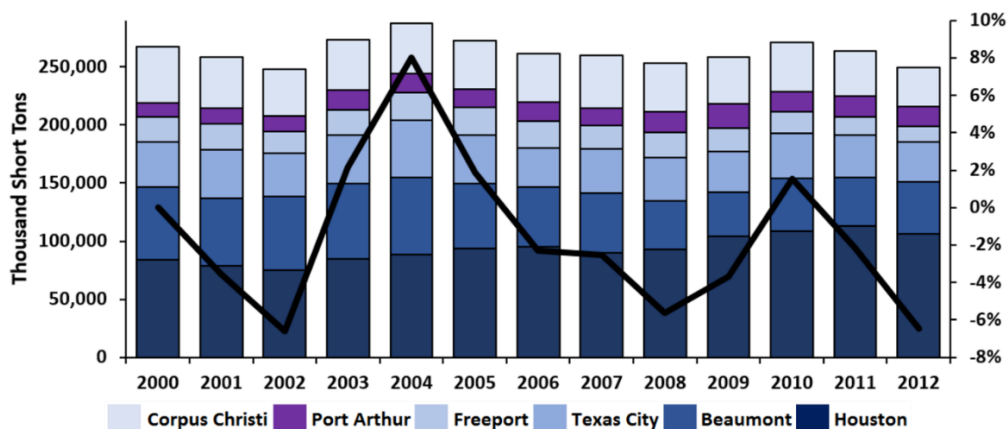


Figure 6.6: Annual total petroleum crude shipments – imports and exports - by port (bars) and respective average growth rate (line).

The refining analysis showed the growth rate of total operable refining capacity remaining relatively flat throughout the decade in contrast to the volatility of port trade. The total operable capacity of the major refining centers increased by 11 percent from 2000 through 2008, followed by a steady flat rate. A notable uptick of an additional 11 percent in operable capacity was observed in 2013 as a result of the Motiva Enterprises Refinery expansion in Port Arthur.²⁴ In summary, the combined operable capacity of the coastal refineries did not fluctuate significantly over the study timeframe. In fact, the 26 state refineries in operation today is the same number as in the 1930s (Texas Office of the Governor, 2005). This lack of new capacity can be explained by the complex, continuous-flow, and capital-intensive nature of the large refining hubs.

While the operable capacity patterns show limited fluctuation, the daily refining operations are in fact very heterogeneous. In addition to operable capacity, petroleum refineries vary in feedstock quality, utilization rates, product type, and product yield. Shifts in any one of these factors can directly impact the operating costs and profit margins of the refiners. Therefore, refineries adjust their configurations and operations in order to accommodate changes in global hydrocarbon supply and demand. A prominent example of changes in feedstock quality is the recent increase of light sweet petroleum supply from unconventional formations. The increase in light sweet crude presents a challenge because many of the Gulf Coast refining hubs have been designed to process heavier Canadian and Venezuelan oil (EIA, 2015). The changing market conditions have prompted some Texas operators to make upgrades to their refineries in order to process the lighter crudes. While these multi-million dollar investments allow the operators to exploit cheaper regional oil supplies, the upgrades do not necessarily increase the operable capacity of the refineries

²⁴ The Motiva Port Arthur Refinery (owned by Shell and Saudi Aramco) increased its capacity from 285,000 bbl/day to over 600,000 bbl/day. The 2013 expansion made the Motiva Refinery the largest refining complex in the U.S.

(Brelsford, 2014). Another important facet of refining operations is the refinery utilization rate. This rate is defined as the amount of feedstock input (primarily crude oil) divided by the total operable capacity. The rate fluctuates in response to multiple factors including maintenance or a lack of product demand. The utilization rate during the study timeframe was at its highest level in 2004, followed by a four year decline (Figure 6.7).

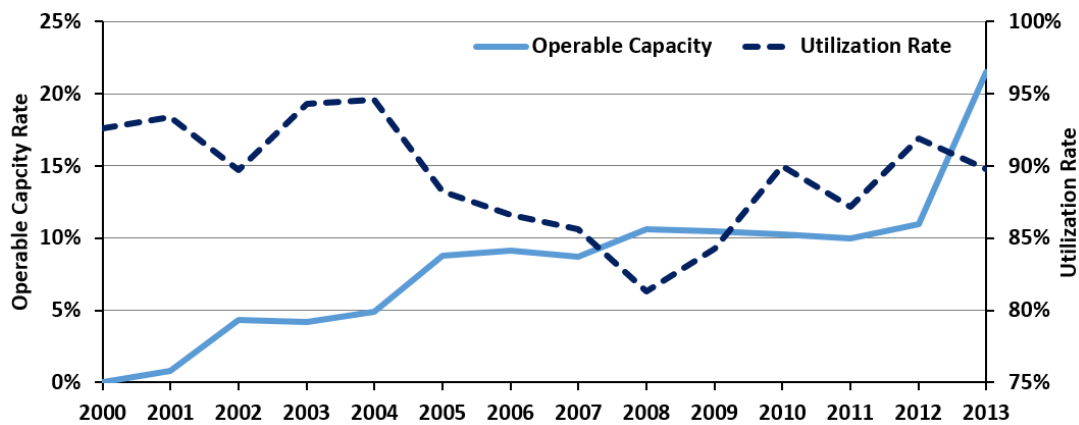


Figure 6.7: Annual operable capacity rate and utilization rate for all Texas Gulf Coast refineries. Chart compiled based on data from the EIA.

A common tool used for assessing the economic conditions of refineries is the 3:2:1 crack spread calculation which roughly estimates the refining profit margins. Crack spreads only evaluate the basic input/output variables of refining operations. They do not take into account all the detailed variables like taxes, overhead, and fixed costs. The 3:2:1 spread reflects the margins based on subtracting the cost of three barrels of oil from the revenues of producing two barrels of gasoline and one barrel of distillate (diesel/jet fuel). This multi-product spread is representative of a typical U.S. refinery whose largest expense consists of crude oil and whose revenues are mostly derived from gasoline and distillate production. Therefore, due to the heterogeneity in refineries, the price and yield volume data used for calculating the crack spread reflects the average refinery along the Texas Gulf Coast

(Figure 6.8). Essentially, this figure illustrates the crack spread or the price gap (profit) between the finished product (revenue) and WTI crude oil (cost). It also highlights the monthly volatility in refining revenues.

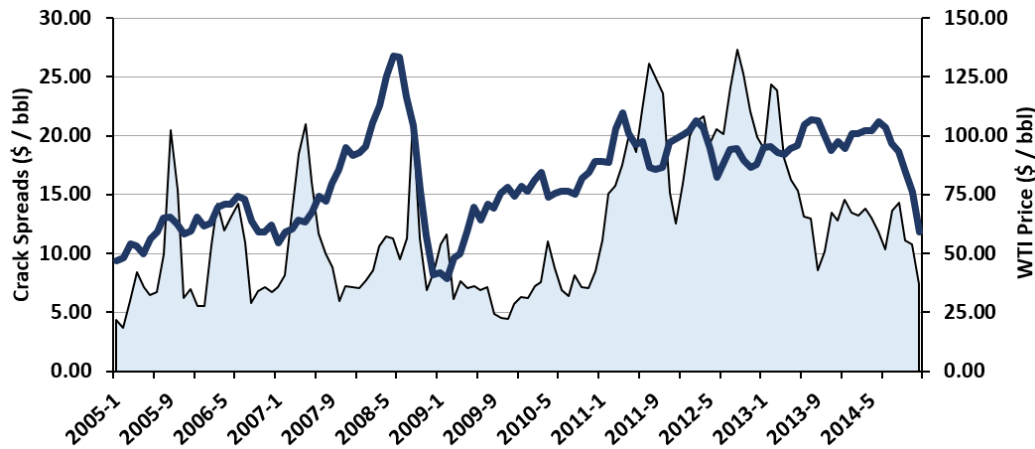


Figure 6.8: Estimated monthly 3:2:1 crack spread for and average Texas Gulf Coast refinery (shaded area) with respect to the WTI oil price (line).²⁵

In order to capture the recent downstream labor trends, employment and wages data were compiled for the major Texas waterborne shipping and refining regions. Confidentiality guidelines prohibit the data to be released at county level, thus the employment and wages were assessed by the respective Metropolitan Statistical Areas (MSAs)²⁶ to provide a general overview of downstream employment and wages. The analysis does not capture the complete impact of ports and refineries on the local economies. To illustrate this under-estimation of impact, the average employment for port operations in the Houston-Sugar Land-Baytown MSA in this analysis was 1,500 employees. However, a detailed 2008 report on the economic impact of Texas ports listed

²⁵ Monthly price, input, and yield data for calculating the 3:2:1 spread was obtained from the EIA.

²⁶ Note: the Corpus Christi MSA represents Nueces County, the Houston-Sugar Land-Baytown MSA represents Brazoria, Harris, and Galveston Counties, and the Beaumont-Port Arthur MSA includes Jefferson County.

the overall direct jobs in the Port of Houston at over 58,000 employees (Siegesmund et al., 2008). In this thesis, it is assumed that the growth rate in port and refining operation jobs will reflect the growth in other related industries.

The port employment analysis is primarily influenced by the Port of Houston which employs the largest share of port-operating employees. The job growth rate indicates a steady increase from 2004 to 2010, followed by a decline through 2012 and an upward growth trend of six percent in 2013 (Figure 6.9). A comparison between the Port of Houston and the Port of Corpus Christi shows contrasting trends. The Corpus Christi MSA witnessed a drop in port operation jobs during the financial crisis, followed by stagnant job growth until 2012 when growth began to increase. In the Houston MSA there was an increase in port operations jobs through the recession before a decline from 2011 to 2013. It should also be highlighted that unlike refining, port employment is influenced by other non-petroleum industries like container shipping and cruise lines.

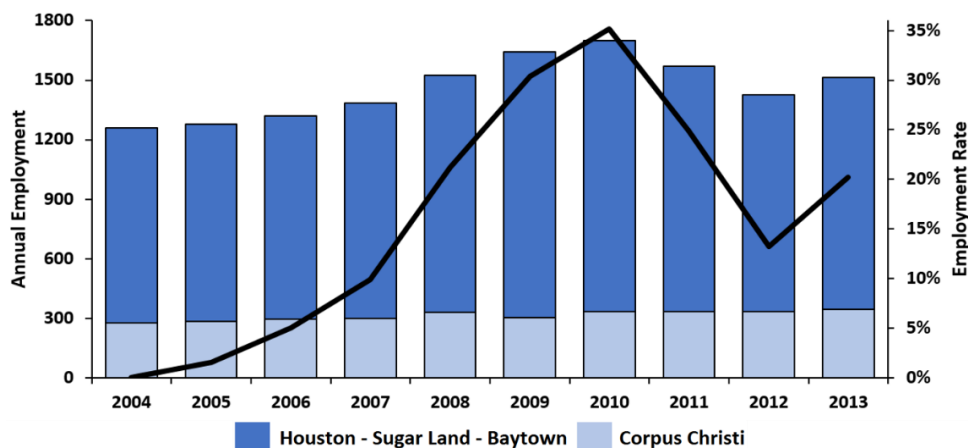


Figure 6.9: Annual employment at ports and harbors by individual MSAs (bars) and the total average growth rate (line).

Employment in refining operations showed diverging patterns among the three MSAs. Refining job growth in the Beaumont – Port Arthur MSA was most consistent.

Despite a small drop in jobs during the recession, the MSA showed a steady average annual growth rate of two percent from 2004 through 2013. The neighboring Houston MSA showed more fluctuation in refining employment with a six percent drop between 2004 and 2005, followed by an 11 percent increase through 2008, before another sharp decline in jobs during the financial crisis. The Houston MSA refining job growth has remained stagnant since. In comparison, the Corpus Christi MSA witnessed wide fluctuations in refining employment during the same timeframe. Initially, the Corpus Christi MSA refining job rate increased rapidly by 14 percent through 2008 but nearly all of these job gains were lost during the recession. However, by 2013, the Corpus Christi MSA recovered the majority of the refining jobs that were lost during the downturn with an overall increase of 10 percent (Figure 6.10).

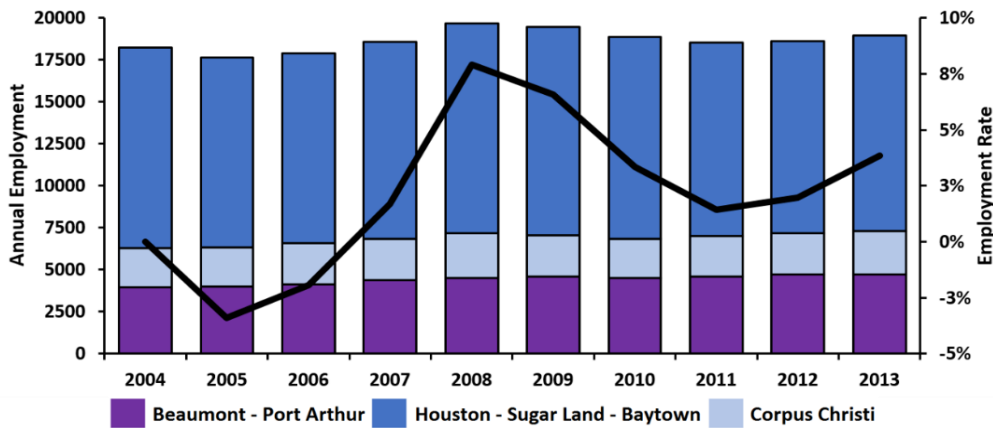


Figure 6.10: Annual employment at petroleum refineries by individual MSAs (bars) and the total average growth rate (line)²⁷.

Overall wage growth between the port operations and refinery jobs follow a similar pattern until 2007. During the period of financial instability (2008-2011), a wide gap

²⁷ Note: the stagnant growth in the Houston MSA places downward pressure on the total job rate. In fact, the Beaumont and Corpus Christi MSAs have witnessed rebounds in jobs since the financial downturn.

emerged between the two sectors with a sharp decrease in refining wages and a short-term spike in port wages until the wage disparity dissipated in 2012 (Figure 6.11).

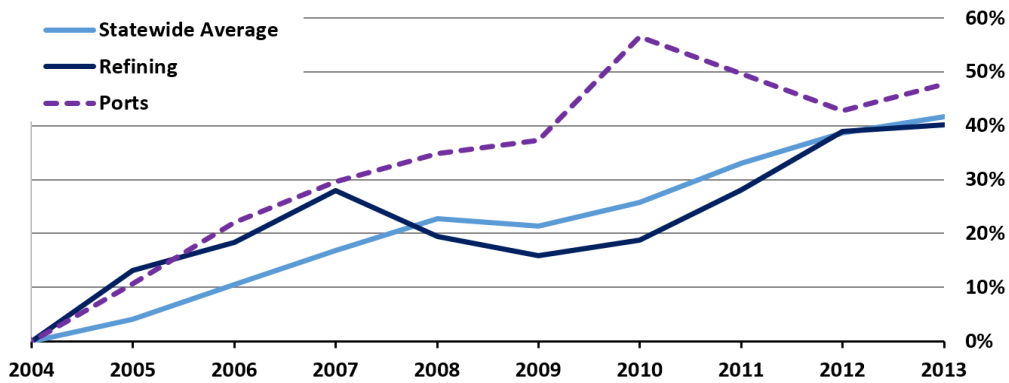


Figure 6.11: Annual wage growth comparison between Gulf Coast refining operations, port operations, and the statewide average wages.

The analysis presented in this section was intended to capture some of the effects of the upstream sector on the downstream sectors. For example, the recent upstream developments have spurred large scale downstream projects that allow for transporting and processing of the new hydrocarbon supplies (Tunstall et al., 2014). Further changing hydrocarbon supply and demand conditions will directly impact refining margins which can ultimately translate into employment shifts. Hence, developments in the upstream sectors must be considered jointly with the downstream sector because the two are intertwined.

The last two chapters captured statewide economic trends over the last decade in respect to the oil and gas boom but they do not account for potential future developments. Ultimately, the future oil and gas developments in these counties will be dictated by fluctuations in commodity prices. Therefore, the following chapter provides a financial sensitivity analysis of the major formations and estimates their break-even prices.

Chapter 7. Hydrocarbon Play Evaluation and Sensitivity Analysis

The previous chapters provided a retrospective analysis of the developments in the statewide oil and gas sector and how they have impacted the local economic conditions of regional counties. This chapter attempts to estimate potential future developments by calculating break-even prices for the five production regions and coupling them with commodity price projections. It is important to remember that each formation varies in factors like geochemistry, extraction costs, operating costs, mineral royalty rates, and production rates. Therefore, in order to capture the listed variations, all five formations were evaluated through the means of decline curve analysis and Discounted Cash Flow (DCF) modeling.

Estimated Ultimate Recovery (EUR) Volume Calculations

As mentioned in Chapter 3, EUR volumes are crucial for conducting financial sensitivity analysis. EUR values are important because the amount of product extracted from a given well coupled with the corresponding commodity price is the ultimate determinant of the well's profitability. This aspect is amplified when considering unconventional formations. As highlighted by Schmoker et al. (1996), the economic risks associated with drilling unconventional wells are dependent on obtaining sufficient production rates, rather than finding hydrocarbon accumulations. In other words, while dry holes are less frequent in unconventional reservoirs, extremely low production rates cause many wells to be deemed uneconomical.

Prior to estimating the EUR values, all the individual production wells were separated into sub-categories to allow for a granular analysis between and within each hydrocarbon production region. First, each well was grouped by its respective hydrocarbon formation-region. Second, the wells within each region were subdivided between oil and

gas production based on the recorded *well type*. Third, the wells were grouped into conventional and unconventional categories based on the recorded *drill type*. Lastly, the *initial production* rates were applied to arrange the wells into performance-based percentiles (Figure 7.1). The last category is most important because it captures the heterogeneity of the well-production qualities within a single region. Wells that are ranked between the 75th and 100th percentiles were classified as optimal while wells ranked below the 50th percentile are sub-optimal. The 50th - 75th percentile bracket was designated as the ‘average well’ of a given area. Figures 7.2 through 7.5 provide the regional initial production rate distribution profiles that were used for designating the well-performance brackets. Appendix A provides more detailed distribution charts for each region.

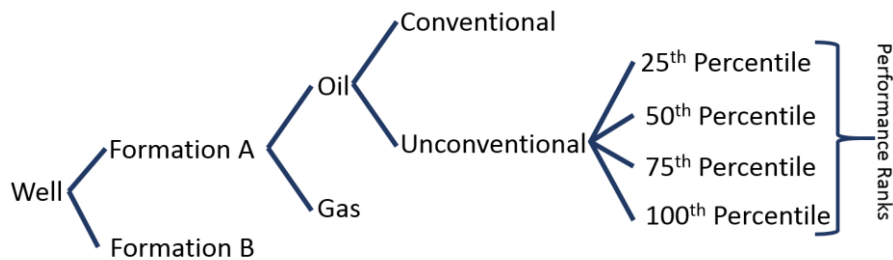


Figure 7.1: Tree diagram of the categorical method used for subdividing the wells.

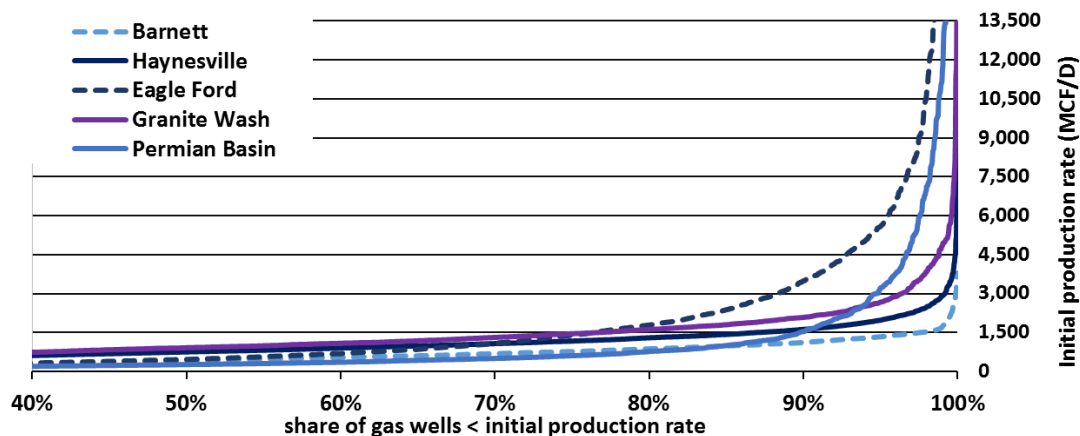


Figure 7.2: Comparison of initial production rate distributions for vertical gas wells.

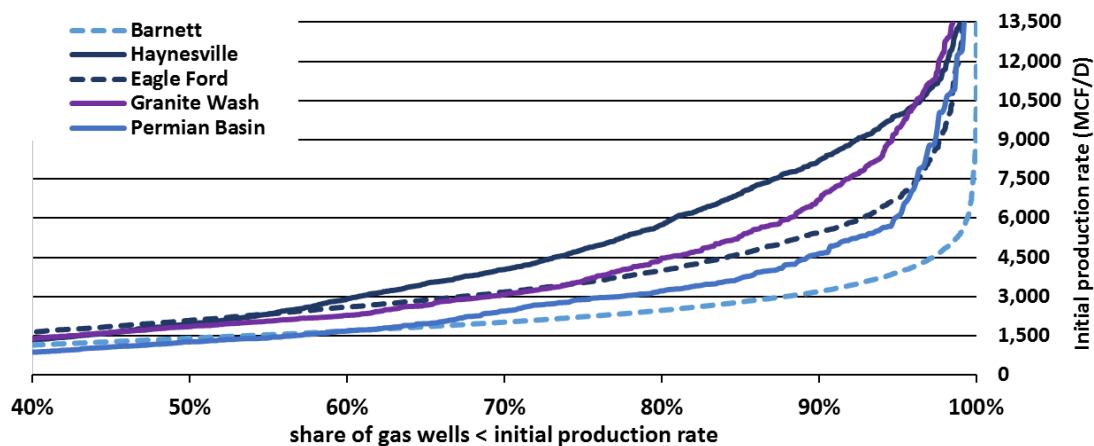


Figure 7.3: Comparison of initial production rate distributions for horizontal gas wells.

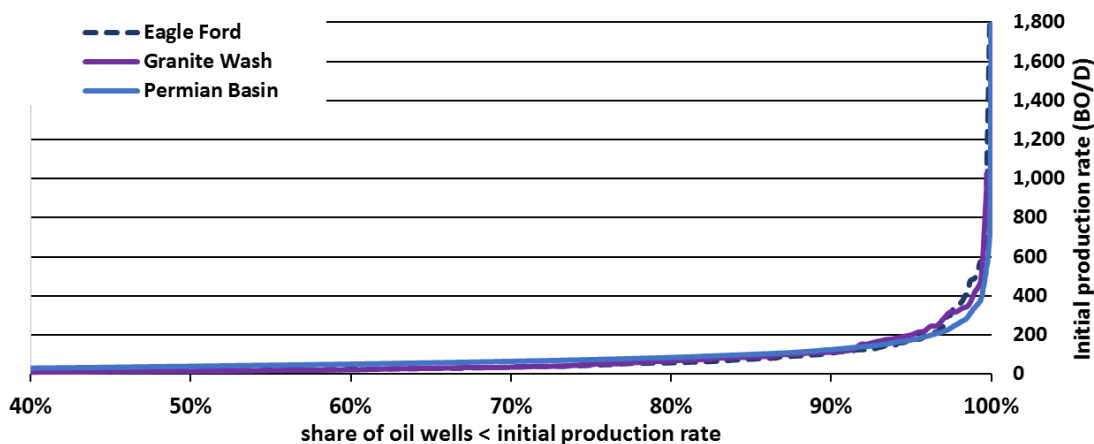


Figure 7.4: Comparison of initial production rate distributions for vertical oil wells.

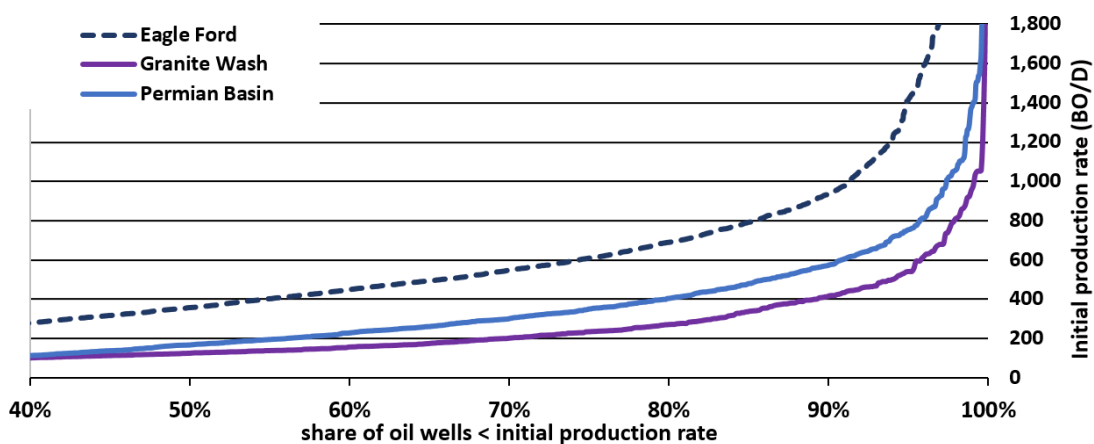


Figure 7.5: Comparison of initial production rate distributions for horizontal oil wells.

In petroleum engineering, rate-time decline curve analysis²⁸ is often utilized when extrapolating the production rate of a given well throughout its lifetime²⁹ (Fetkovich, 1980; Baihly, et al., 2010). These methods are strictly empirical and are based on the typical behavior of oil and gas wells whose initial production rates decline rapidly in response to decreasing reservoir pressure, followed by a low production rate for many years. In addition to estimating the future production rates, decline curve analysis provides an estimate of the ultimate recovery volume of a given resource.

Decline curves and EUR values were calculated for each formation-area by applying the commonly used Arps rate-time equations (Arps, 1945). Most of the equation variables were collected from the DrillingInfo database while the b-factors were calculated by fitting the estimated decline curve functions to historical well decline rates. The following Arps formulas for a hyperbolic decline were applied to each of the formations:

$$a_i = \frac{1}{b} [(1 - d_i)^{-b} - 1]$$

$$q(t) = \frac{q_i}{(1 + b a_i t)^{\left(\frac{1}{b}\right)}}$$

$$Q = \frac{q_i^b}{a_i(1 - b)} (q_i^{(1-b)} - q^{(1-b)})$$

Where:

a_i = nominal decline rate

b = decline exponent constant (b -factor)

d_i = initial decline rate

$q(t)$ = production rate at time t

q_i = initial production rate

Q = cumulative production

²⁸ Often referred to as ‘type-curve modeling’.

²⁹ A single well can produce for decades or until its production costs begin to outweigh its revenues.

Consistent with Baihly et al. (2010), cumulative hydrocarbon production continually increases over time in response to growing technological improvements and efficiency gains among the operators. Figure 7.6 illustrates this upward trend in per-well production profiles for new wells drilled in the Eagle Ford Shale.

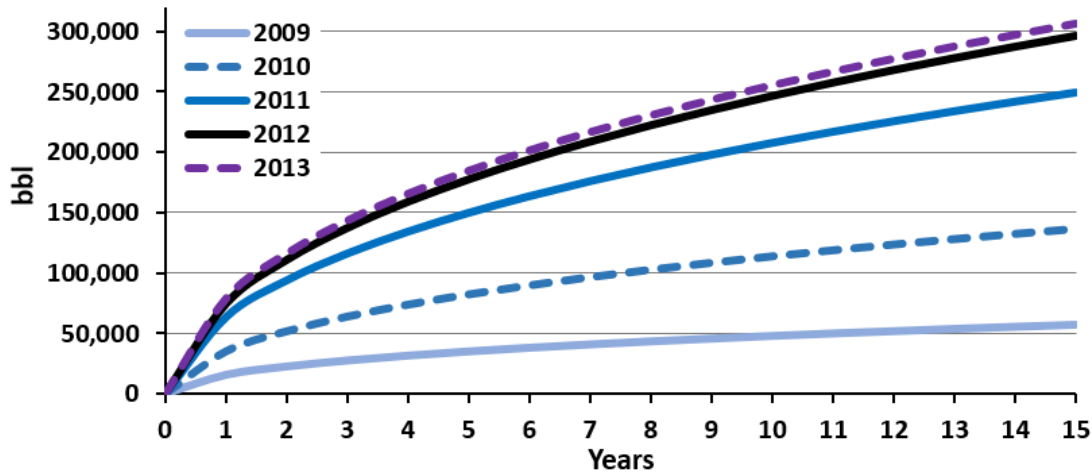


Figure 7.6: Cumulative oil production improvements over time in the Eagle Ford region.

Given the pattern in Figure 7.6, it was assumed that production volumes of future wells will either continue to improve or remain constant. Therefore, instead of using all the available production data (dating back to 2000), only the wells that were drilled in the last five years (2009-2013) were included in the decline curve analysis to reflect the most recent drilling and production technology. Once the individual decline curves were estimated, the production rates were extrapolated over 15 and 20 year timeframes. It is assumed that a 15 year lifespan captures most of the EUR of a given well based on the typical behavior of completed wells whose initial production rates are exceptionally high followed by a steep year-over-year decline. Figures 7.7 through 7.10 illustrate the different unconventional well type-curves and their cumulative production growth.

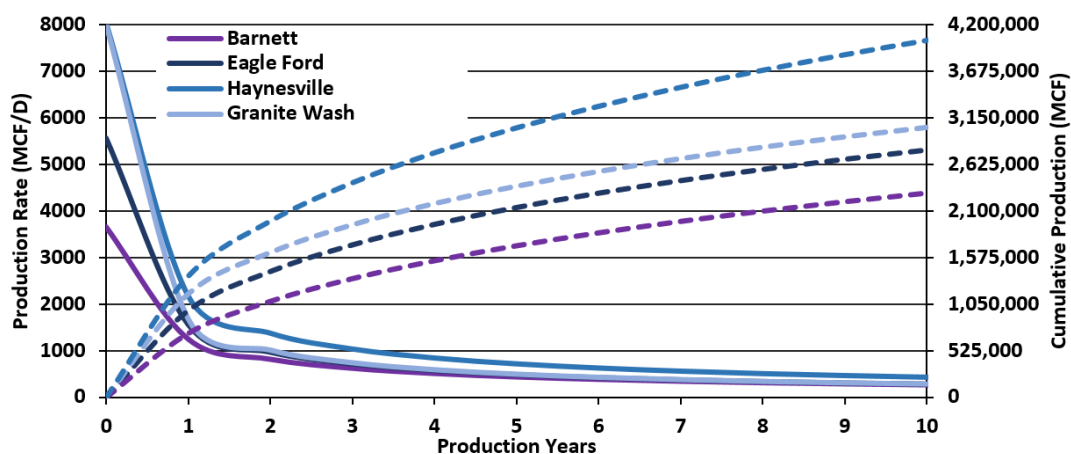


Figure 7.7: Decline rates (solid lines) and production (dashed lines) of optimal gas wells.

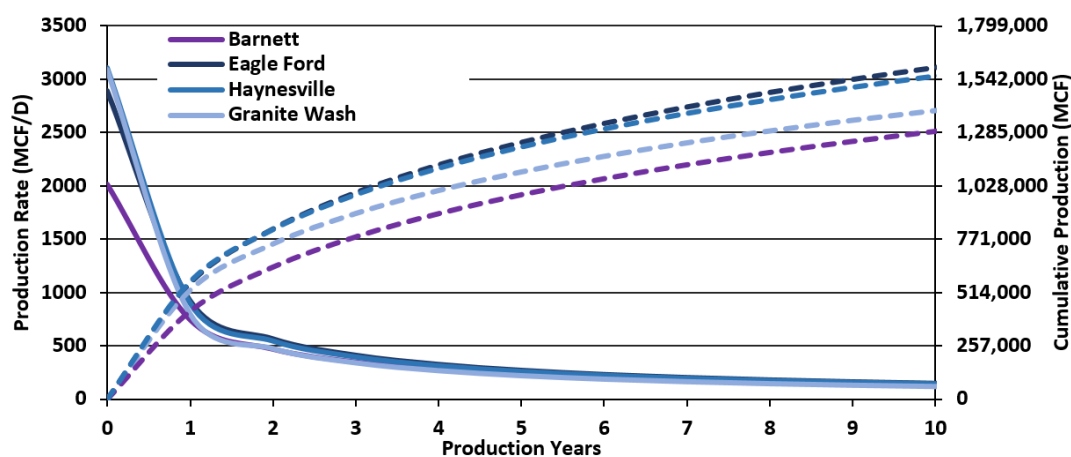


Figure 7.8: Decline rates (solid lines) and production (dashed lines) of average gas wells.

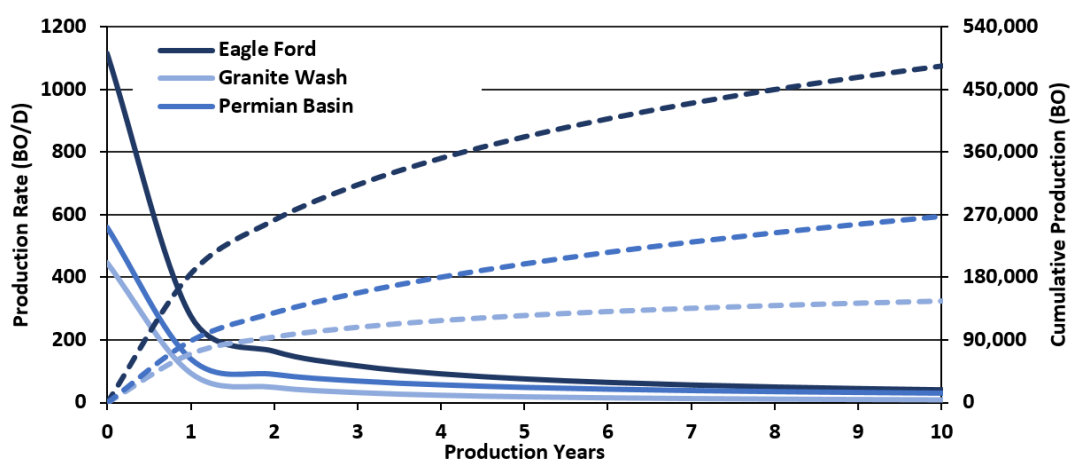


Figure 7.9: Decline rates (solid lines) and production (dashed lines) of optimal oil wells.

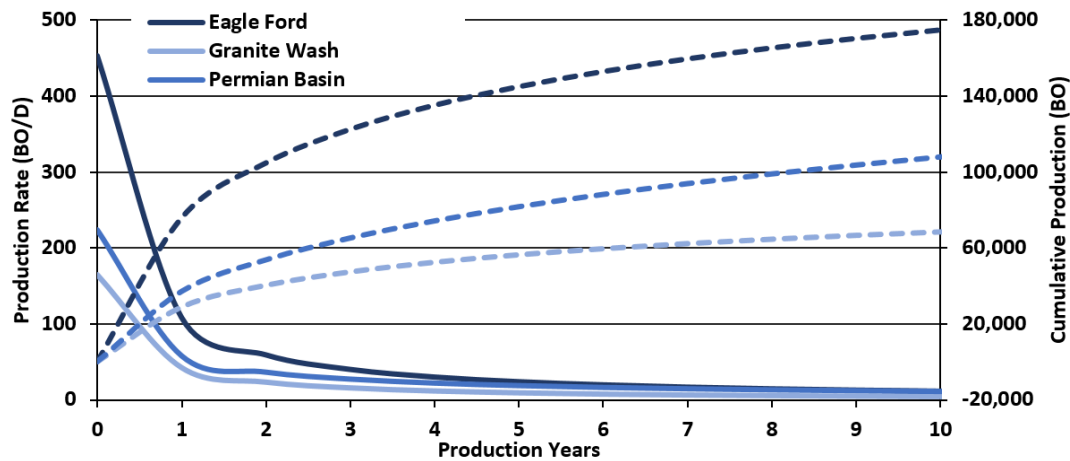


Figure 7.10: Decline rates (solid lines) and production (dashed lines) of average oil producing wells.

Another assumption made in this analysis was that all of the production wells within a formation-area would behave similarly. This geographic clustering of wells was intended to provide an ‘average well’ representation for each region, however, broad variations in pressure and fracture networks make it more difficult to present an ‘average well’ estimate in a particular region. Previous studies have attempted to reduce the effects of petrophysical heterogeneity by focusing only on the core areas of the formations (Baihly et al., 2010). Indeed, such an approach reduces the variation, yet it also skews the decline curves to resemble the more productive ‘sweet spots’ of a shale formation. Gülen et al. (2013) conducted a very detailed analysis of the Barnett Shale and handled the heterogeneity problem by separating the production areas into 10 productivity tiers. The goal of this thesis is to provide a holistic analysis of the statewide economic trends and the petrophysical heterogeneity issue is beyond the scope of this work. Instead, rough estimates of the EUR values are provided in this chapter. Table 7.1 presents a summary of the decline curve analysis and includes the parameter estimates used in the decline curve equations along with the respective EUR values for 15 and 20 year timeframes. Note that the listed results

are representative of an optimal-performance horizontal well (top 25th percentile) for each region. The detailed output results which include all the well quality percentile brackets are included in Appendix B.

Region	Well type	Drill type	* q_i	d_i	b - factor	** 15-yr Q (EUR)	** 20-yr Q (EUR)	n
Eagle Ford	gas	vertical	2,298	66%	0.8	1,311,830	1,387,579	133
	gas	horizontal	5,568	72%	1.2	3,213,910	3,532,552	578
	oil	***vertical	144	67%	0.9	84,390	90,224	142
	oil	horizontal	1,116	75%	1.1	547,673	594,454	830
Barnett	gas	*** vertical	1,122	64%	1.1	804,751	881,398	1,054
	gas	horizontal	3,657	66%	1.3	2,700,456	3,009,303	1,230
Haynesville	gas	vertical	1,702	73%	1.1	902,156	980,831	1,009
	gas	*** horizontal	8,045	73%	1.3	4,681,667	5,190,944	658
Permian	gas	***vertical	3,037	70%	0.8	1,516,704	1,598,573	547
	gas	***horizontal	3,960	63%	1.1	2,927,116	3,208,562	116
	oil	vertical	197	67%	1.2	134,926	148,874	1,515
	oil	horizontal	561	75%	1.4	315,206	352,132	311
Granite Wash	gas	vertical	2,498	78%	0.9	971,980	1,029,107	257
	gas	horizontal	8,008	79%	1.2	3,474,933	3,798,547	285
	oil	***vertical	152	80%	0.9	53,979	57,048	59
	oil	horizontal	446	79%	0.8	156,770	163,923	165

* Gas measured in MCF/D and oil measured in BO/D.

** Gas measured in MCF and oil measured in BO.

*** Due to a limited number of wells (n), a longer time period (outside the 2009-2013 window) was used for the decline curve analysis.

Table 7.1: Coefficients applied in the decline curve analysis and the computed EUR values. Note: the listed results are representative of an optimal-performance horizontal well (top 25th percentile).

Discounted Cash Flow Model

In order to evaluate the break-even prices for each region, discounted cash flow (DCF) models were constructed using the computed production profiles from the previous section. DCF analysis is a common financial method used for evaluating the feasibility of potential projects. For example, in the oil and gas business, a decision to commence drilling requires an estimate of the upfront capital costs and projected future cash flows from the venture. In a DCF model, the value associated with starting a project can be derived from

the Net Present Value (NPV). An NPV is calculated by subtracting the present value of the project's initial costs from the present value of future cash flows and can be expressed as follows:

$$NPV = -C_0 + \sum_{t=1}^{t=n} \frac{CF_t}{(1+r)^t}$$

Where:

C_0 = upfront costs of the project

CF = cash flow

r = discount rate - reflecting the riskiness of the project

t = time period in years

n = lifetime of the project in years

A positive (negative) NPV suggests that under the assumed parameters and conditions the project's discounted expected future cash flows exceed (are less than) the upfront costs. Projected cash flows are calculated by subtracting predicted future costs from future revenues of the proposed project. Cost assumptions for horizontal wells are listed in Table 7.2. These assumptions are based on averaging multiple project cost values that were collected from industry presentations, academia papers, and conference proceedings. In addition to the listed costs, state severance taxes were applied to the gas-producing wells (7.5%) and oil-producing wells (4.6%). Drilling and completion of conventional vertical wells is typically 1/3 the cost of horizontal wells (Barker, 2013). Therefore, the CAPEX values were accordingly adjusted when evaluating the vertical wells.

Region	Assumed Variables	Low	Base	High
Eagle Ford	OPEX (\$ / MCF)	1.25	1.30	1.35
	OPEX (\$ / BO)	3.00	6.90	13.00
	CAPEX (\$ / well)	5,800,000	7,500,000	9,500,000
	Royalty Rate (%)	20%	25%	25%
	Average Well Spacing (acres)	40	55	80
	Leasehold Cost (\$ / acre)	14,000	19,500	25,000
Barnett	OPEX (\$ / MCF)	0.51	0.97	1.85
	CAPEX (\$ / well)	1,400,000	2,970,000	4,000,000
	Royalty Rate (%)	20%	23%	25%
	Average Well Spacing (acres)	38	51	75
	Leasehold Cost (\$ / acre)	2,500	9,250	25,000
Haynesville	OPEX (\$ / MCF)	0.25	1.43	2.89
	CAPEX (\$ / well)	5,000,000	8,410,000	12,000,000
	Royalty Rate (%)	20%	25%	30%
	Average Well Spacing (acres)	60	82	107
	Leasehold Cost (\$ / acre)	5,000	18,333	25,000
Permian	OPEX (\$ / BO)	7.00	8.60	11.30
	CAPEX (\$ / well)	4,500,000	7,000,000	9,000,000
	Royalty Rate (%)	20%	22%	27%
	Average Well Spacing (acres)	90	138	160
	Leasehold Cost (\$ / acre)	6,500	6,500	6,500

Table 7.2: Primary cost assumptions for horizontal wells in the low, base, and high cases. The data was compiled from numerous industry and academia publications including, journal articles, conference proceedings, and investor presentations. These sources are marked by a double asterisk in the works-cited section.

After the assumed costs were established, the projected annual revenues were calculated. Oil and gas revenues are primarily dependent on two factors: the price and the extracted quantity of a given commodity. The estimated projected production volumes were multiplied by forecasted prices from the EIA 2014 Annual Energy Outlook report to determine the revenues. The report included three price scenarios which conveniently fit with the three risk scenarios. Revenues from natural gas, however, were more difficult to estimate because each formation varies widely in natural gas composition. For instance, the Haynesville Shale is predominantly a dry gas (methane) formation while the Eagle Ford Shale is considered a wet gas play as it produces significant amounts of NGLs. This aspect

is important to consider because unlike natural gas, NGLs typically follow the price of oil and often have higher prices (Figure 7.11).

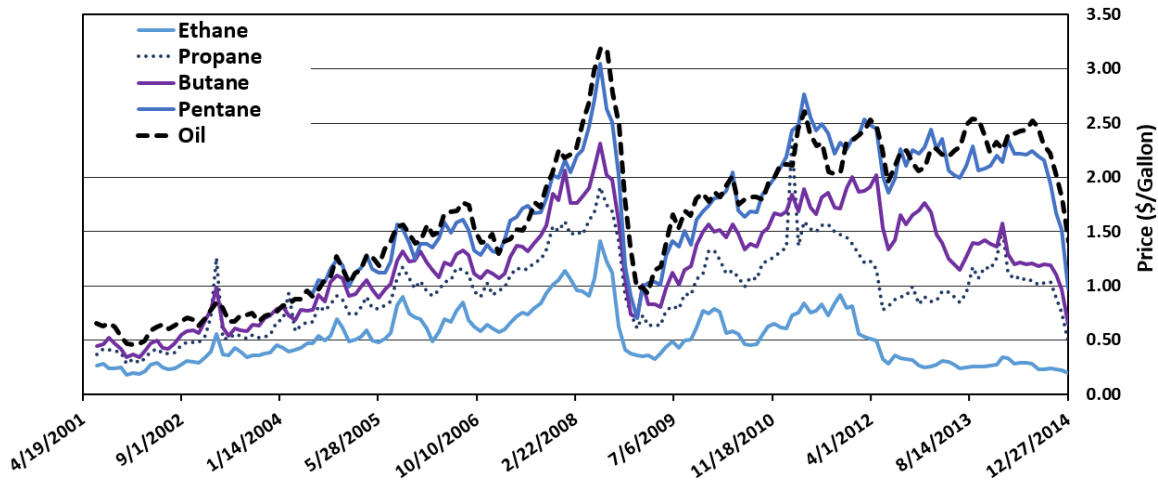


Figure 7.11: Historic Mont Belvieu NGL prices in respect to the WTI price of oil. Chart compiled based on data from Bloomberg and the EIA.

As seen in Figure 7.11, there exists a strong relationship between the price of oil and the prices of various NGLs. The EIA annual report did not provide price projections for NGLs. Nevertheless, the relationship between oil and NGLs allowed for calculating reasonable price projections. Based on data from 2001 through 2014, regressions were constructed in order to estimate the linear relationship between the price of oil and the price of various NGLs (see Figure 7.12). Accordingly, these formulas were coupled with the EIA oil price forecasts in order to approximate the future prices of NGLs under the assumption that these price relationships will hold in the future.

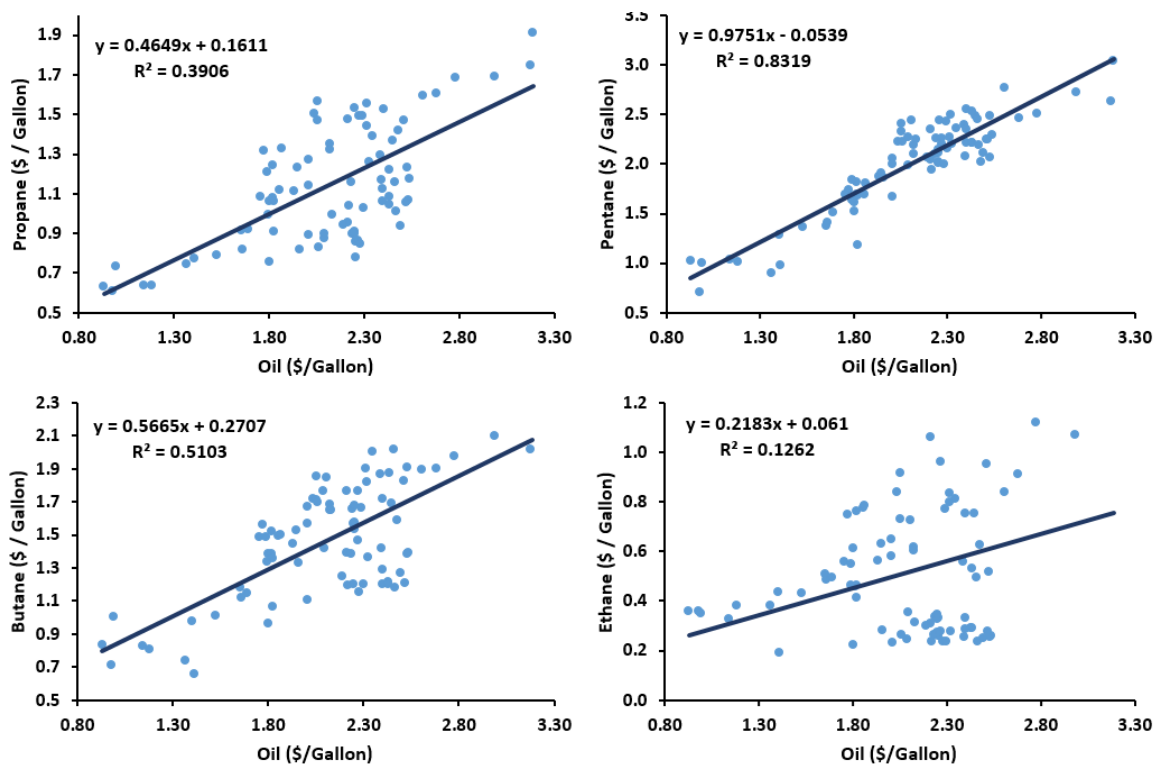


Figure 7.12: Regression plots indicating the relationship between the various NGL prices and respective oil prices.

Having projected the NGL prices, it was also important to accurately represent the NGL composition of each hydrocarbon region. Accomplishing this required a collection of geochemical data for each formation. Through literature review, a wide collection of geochemical samples was compiled for four major formations (Jenden et al., 1988; Rice et al., 1988; Hill et al., 2007; Bullin and Krouskop, 2009; Rodriguez and Philip, 2010; George and Bowles, 2011; Todd, 2011; Ellis, 2014). Table 7.3 provides a summary of the play compositions. Samples with the highest methane concentrations were deemed as representative of dry-gas windows. Conversely, wet-gas windows were represented by samples with the lowest methane concentrations.

Formation	Gas Window	Methane	Ethane	Propane	i-Butane	n-Butane	Pentane	Nitrogen	CO ₂
Barnett	Average:	85.36	7.65	2.55	0.43	0.71	0.42	1.00	1.47
	Dry:	96.08	1.52	0.06	0.00	0.00	0.00	0.51	1.83
	Wet:	75.04	12.43	5.53	0.81	1.69	1.07	1.42	0.90
Granite Wash	Average:	81.33	6.89	3.11	0.45	0.85	0.46	6.09	0.47
	Dry:	89.74	5.49	2.19	0.29	0.56	0.26	0.61	0.53
	Wet:	70.75	8.06	3.59	0.47	0.87	0.46	15.47	0.32
Eagle Ford	Average:	77.06	13.01	4.94	0.92	1.17	0.82	0.21	1.18
Haynesville	Average:	95.66	0.59	0.10	N/A	N/A	N/A	0.23	3.31

Table 7.3: Geochemistry of natural gases separated by individual formation and gas window. The values are presented in mole fractions.³⁰

Breakeven Analysis

Having assembled the assumed costs and hydrocarbon compositions of each production area, a breakeven price analysis was performed. The economic analysis accounted for both, vertical and horizontal wells. However, the majority of the vertical wells required unrealistically high commodity prices in order to be deemed economical. Provided that such prices are unlikely to materialize, the vertical wells were excluded from the following discussion. The few Permian Basin vertical well scenarios that were profitable are included in Table 7.4.

The economic breakeven analyses were based on fixed commodity prices and a discount rate of 10 percent. Table 7.4 lists all the estimated breakeven prices. It should be emphasized that project operating costs and capital costs can fluctuate dramatically between different operators, formations, and even time periods³¹. These variations will directly influence the breakeven prices.

³⁰ Permian Basin was excluded from the composition analysis partly because it is dominated by oil production and partly because there are too many different formations with varying gas content.

³¹ In response to growing demand, water costs, leasing rates, and royalty rates tend to increase as regional drilling expands over time.

Formation	Well Qual.	Breakeven*	Formation	Well Qual.	Breakeven*
Barnett - Wet Gas**	25th %	3.17	Barnett - Dry Gas**	25th %	3.86
	50th %	5.74		50th %	5.87
	75th %	8.15		75th %	7.75
Barnett - Avg. Gas**	25th %	3.59	Eagle Ford - Gas**	25th %	7.38
	50th %	5.86		50th %	12.44
	75th %	7.97		75th %	19.90
Haynesville - Gas**	25th %	6.36	Eagle Ford - Oil	25th %	39.02
	50th %	13.24		50th %	90.61
	75th %	26.14		75th %	149.80
Permian Basin-Oil	25th %	59.29	Permian Basin-Oil***	25th %	54.00
	50th %	130.70		50th %	133.93
	75th %	280.77		75th %	244.73

* Gas estimates in \$/MCF (Henry Hub), oil estimates in \$/bbl (WTI).

** Geochemistry composition (refer to Table 7.2.2), NGL prices are based on the base case oil projection.

*** Vertical Wells

Table 7.4: Estimated breakeven prices for various well performances and play composition scenarios.

Under the given assumptions, the analysis estimates that the Eagle Ford area has a lower breakeven price than the Permian Basin in terms of unconventional oil production. However, the opposite is true for vertical wells because the decline curve analysis shows a 15 year EUR for a vertical Permian Basin oil well was nearly 70 percent higher than that of an Eagle Ford vertical well. The breakeven analysis also indicates that the Barnett wells are the most economical within the gas-production category for an average well. To put it in perspective, the breakeven prices for the Haynesville wells were estimated to be more than twice as high as those of the Barnett wells. This pattern is analogous to the findings of Baihly et al. (2010) who also indicate a large difference in the breakeven commodity prices between the core production areas of these two gas formations. The wide separation could be the result of high project costs that are associated with the Haynesville Shale due to its greater depth and lack of NGLs in the formation. With the price of natural gas continuing to decline, it may be a while before the Haynesville Shale becomes profitable

again. When considering the multitude of aspects related to each formation, the complexity of estimating breakeven prices becomes clear³². For example, incorporating distribution and processing costs will likely adjust the breakeven estimates. Such information, however, is difficult to obtain. Figures 7.13 illustrates how the four primary formations contrast in respect to their breakeven prices.

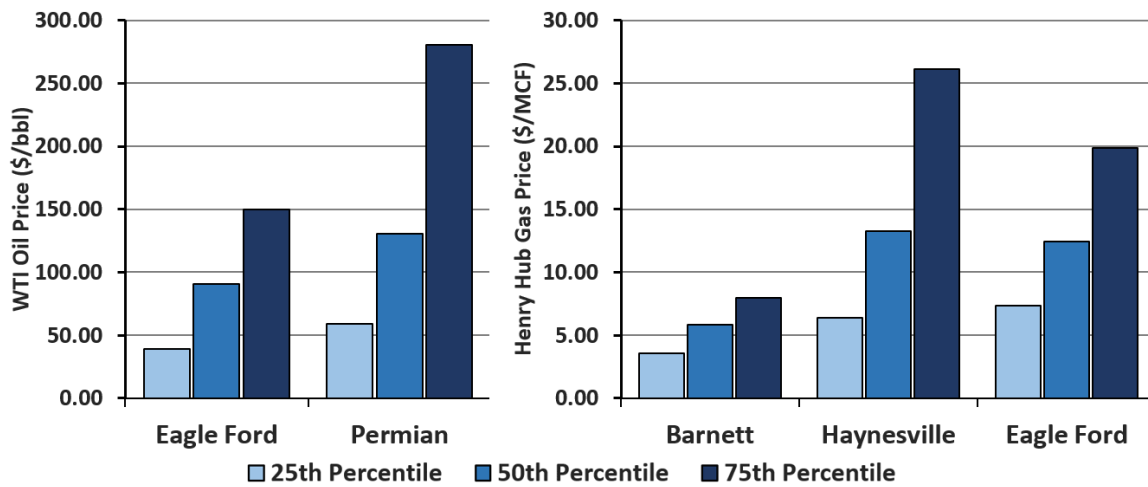


Figure 7.13: Estimated breakeven prices for horizontal wellbores within major oil (left) and gas (right) plays under the ‘average’ scenario. Each play is separated by potential well-performance brackets (25th percentile = exceptional, 75th percentile = poor performance).

As demonstrated in the previous figure, the breakeven prices are highly dependent on factors like project costs and well performance. The relationship between assumed capital costs and breakeven prices is captured in Figure 7.14. Similarly, Figure 7.15 shows the relationship between well performance and breakeven prices.

³² Reuters recently compiled a list of analysts’ breakeven estimations for major shale formations. In the case of Eagle Ford, breakeven price estimates ranged anywhere from \$43 to \$90 per bbl (Reuters, 2014).

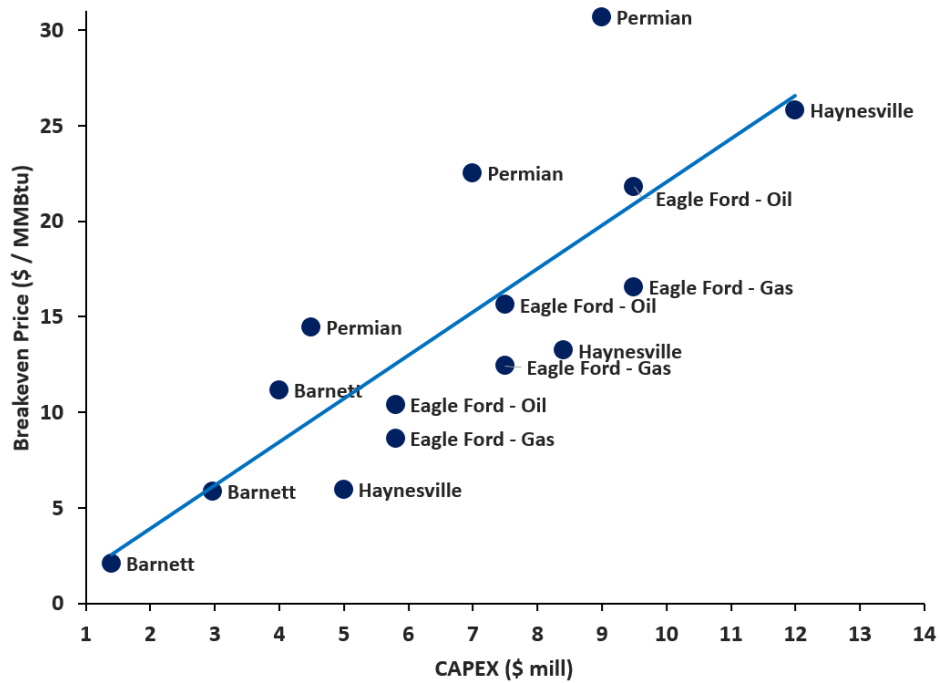


Figure 7.14: Breakeven prices for 50th percentile horizontal wells in respect to their assumed CAPEX values (low, base, and high cost scenarios).

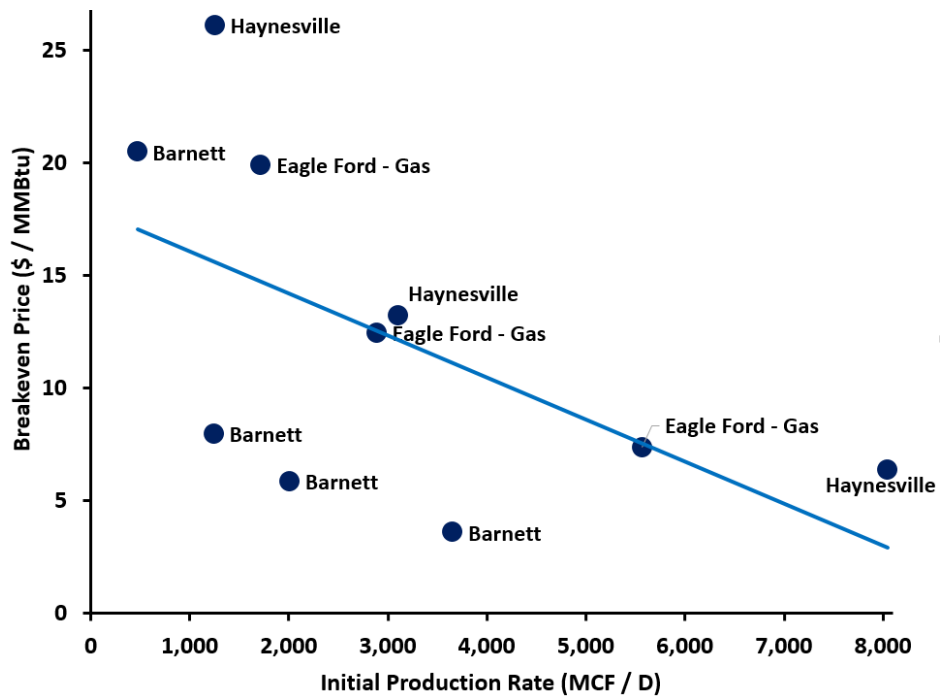


Figure 7.15: Breakeven prices for 50th percentile horizontal wells in respect to their production performances (low, base, and high cost scenarios).

The two previous figures were compiled in order to illustrate the importance of two factors: project cost efficiencies and initial production rates. Because higher costs and lower production rates can render an oil and gas venture uneconomic, efficiency gains and cost reduction are the most important tools that operators can exploit as a means to bolster their profits and reduce market price risk³³. This aspect was captured in Section 7.1 where cumulative production in the Barnett Shale was shown to improve over time in response to growing technological improvements and efficiency gains among the operators.

The nascent nature of unconventional exploration leaves room for efficiency growth. Just in the last decade, the industry has increased its use of innovative techniques like multi-stage fracturing, stacked laterals, multi-well pads, and distributed automation (Seale 2007; Eckley et al., 2014; Thuot, 2014). All of these improvements have translated into per-well productivity growth across the major U.S. shale plays (EIA, 2014h). Despite these innovative technologies, each project is constrained by the geologic quality of each reservoir and the market price. In fact, development of unconventional formations follows a cyclical pattern. Initially, costs decline and production rates increase as operators seek out the favorable core-areas of the play. Then, as the prime reservoir areas are developed, operators begin to transition toward less-favorable and more costly regions (Reeves and Koperna, 2007). Ultimately, as demonstrated in this chapter, the profitability of a project is dependent on the commodity price. Under current market conditions, the majority of the assumed cost scenarios are not profitable, even in the oil and NGL-rich regions. However, commodity prices will inevitably rebound and these regions will likely witness future resource booms.

³³ This does not account for financial instruments like hedging that are commonly exploited in order to reduce market risk.

Chapter 8. Discussion and Policy Implications

Several recent research articles have examined economic patterns related to the unconventional oil and gas booms of the early 21st century (IHS Global, 2011; Maniloff and Mastromonaco, 2014; Weber, 2014; Feyrer et al., 2015; Hausman and Kellog, 2015). Each of these studies provides an important, broad overview of the economic impacts across the lower 48 states. In contrast, the assessment provided in this thesis concentrates on the State of Texas where the oil and gas industry is an integral part of the economy. This granular analysis provides multiple benefits. First, it allowed for a comprehensive dataset to be assembled which would have been more difficult to accomplish across multiple states. Second, Texas unconventional formations are geologically-diverse; in particular there are both, very wet and very dry plays. Third, the focus on Texas provided a relatively lengthy timeframe because unconventional drilling in the state dates back to the early 2000s. Lastly, because the study is isolated within a single governing state, it provides more regulatory and economic consistency as a result of a ‘closed system’ analysis. This final chapter provides an overview of the findings reported in this thesis. Additionally, the last section provides a discussion about potential policy implications and how policy can retain, stabilize, or hinder growth in hydrocarbon producing regions.

Discussion: Research Findings

Scarcity of accessible conventional domestic oil and gas resources spurred efforts to tap unconventional resources which have historically been considered uneconomical to exploit. Not only has this newfound supply of domestic hydrocarbons reduced the trade deficit, but it directly bolstered the economies of counties that overlie the formations. By analyzing the economic and production trends, this study underlines the complicated dynamics of rapid resource development. In particular, the analysis captured how steep

growth in oil and gas operations was accompanied by an influx of labor, growth in local sales, housing shortages, and increased traffic accidents. In the case of average wages, the findings suggest a limited effect.

The research shows that economic growth among the primary production regions was uneven. For example, while the Barnett Shale, Permian Basin, and Eagle Ford Shale counties experienced substantial job growth, the Haynesville Shale region witnessed relatively limited economic growth during the energy boom period (Figure 8.1). This contrast may largely be the result of varying shale characteristics including, depth, geochemistry, complexity of fracture networks, and reservoir pressure. All of these factors directly impact the costs associated with shale development. Particularly, geochemistry of the formations played an important role during this recent boom. While dry gas formations proved to be profitable in the early stages of the boom, their growth was hindered after natural gas prices plummeted. In the latter period of the boom, oil and NGL-rich reservoirs emerged as the profitable plays. This price-dependent aspect was further considered in Chapter 7 where it was demonstrated that relatively high commodity prices are required in order to sustain long-term unconventional development.

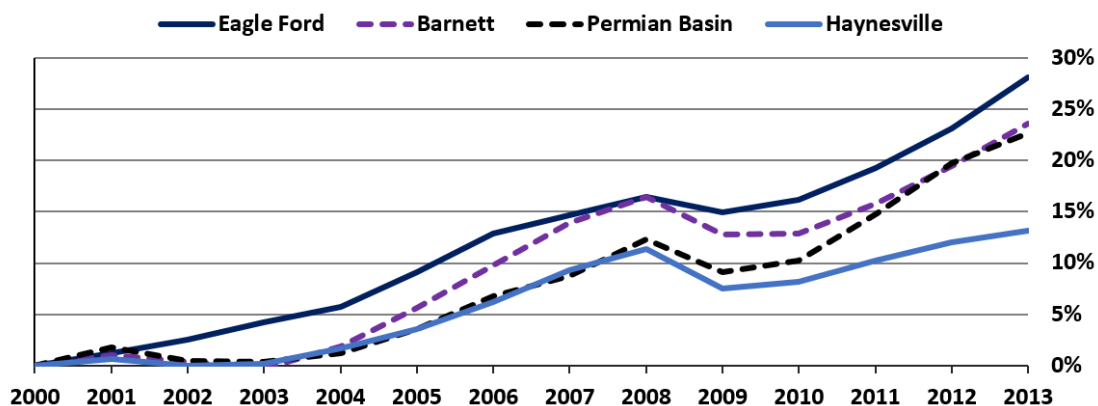


Figure 8.1: Variations in total employment growth between the major production regions.

While the overall job markets in the major boom areas showed somewhat similar growth trajectories, other economic measures were more variant. During the study timeframe, hospitality-related sales in the Eagle Ford Shale and Permian Basin regions showed exceptionally rapid growth rates (Figure 8.2). Such high growth rates did not occur in the Barnett Shale area even though it also witnessed a natural gas boom. The difference is attributed to the rural nature of West and South Texas. These predominantly rural communities are not accustomed to high population levels and require temporary housing (e.g. hotels and man-camps) to be constructed in order to accommodate the inundation of workers. Whereas, the Barnett Shale stretches across a mostly urban region of North Texas and workers can commute from the nearby Dallas - Fort Worth Metroplex. A similar occurrence was observed in the traffic accident analysis. The higher populated counties of the Barnett region placed downward pressure on the overall traffic accident rates, while traffic accident rates in rural south and west Texas seemed to skyrocket due to a limited number of pre-boom accidents.

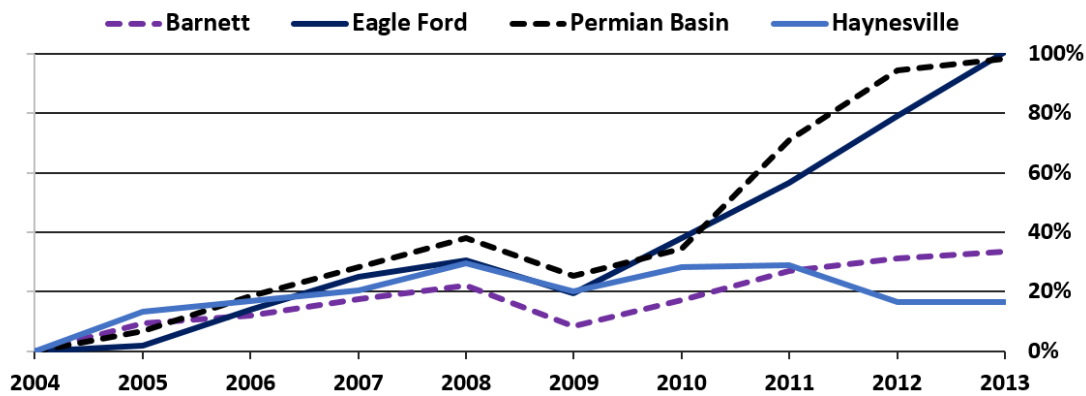


Figure 8.2: Variations in hotel room-nights sold between the major production-regions.

Hotel revenues and overall taxable sales growth varied in the oil and gas production regions. In particular, the Eagle Ford region of South Texas showed a spike in the last year

of the study. This sudden growth even outpaced the sales growth of the Permian Basin counties. Nevertheless, gross sales in the Permian Basin and Eagle Ford communities witnessed some of the highest growth rates in the state. Starting in the latter part of the study timeframe, economic growth in these two regions diverged from the other study areas (Figure 8.3).

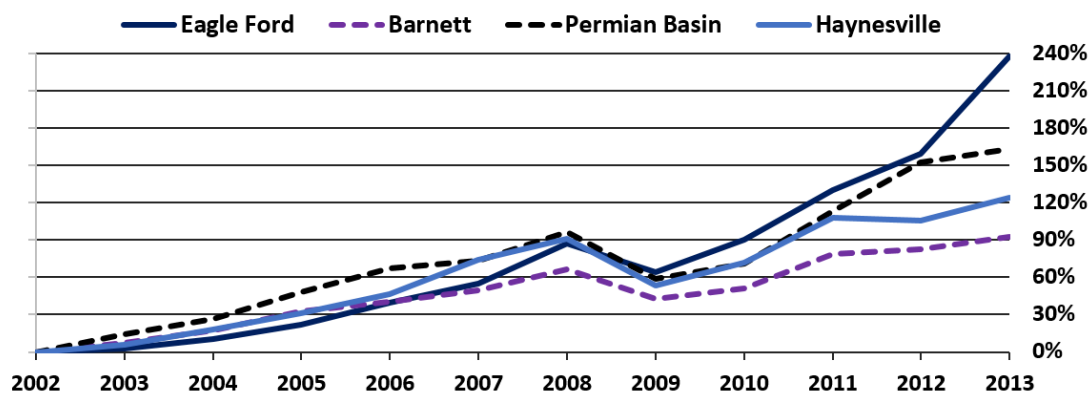


Figure 8.3: Variations in gross sales between the major production regions.

From the previous three charts it is evident that economic patterns varied between the four major study areas during the recent energy boom. This regional contrast underlines the need for detailed regional studies in order to better grasp the impact of energy development on local economies. The presented work was formulated around this exact goal. The research was separated into two distinct sets of analyses. The first analysis (Chapters 4-6) provided a retrospective measure of the production and economic patterns in both, the upstream (direct) and downstream (indirect) counties of the state. The second analysis estimated potential future developments in these regions based on price projections and break-even estimates. Generally speaking, this research highlights the interrelation between local economies and global commodity markets. It further demonstrates that the viability of capital-intensive unconventional drilling is a function of

the price of oil and gas. While factors like futures contracts (hedging) and efficiency gains may extend drilling projects during price downturns, eventually, a prolonged period of lower prices will discourage operators from pursuing development of the hydrocarbon fields. Therefore, the economic benefits and drawbacks associated with regional production are closely tied to the respective global and national commodity prices. A sudden decline in demand or an oversupply of hydrocarbons can leave many upstream investments stranded, especially where there is downward pressure on prices.

Inevitably, prices will once again reach a level that supports new oil and gas projects. Thus, the results of this research and others like it should be carefully evaluated in respect to the costs and benefits of future resource booms. The recent unconventional energy boom has presented rural counties throughout Texas with plentiful economic benefits. Unfortunately, there are also drawbacks associated with rapid resource development. The two most prominent problems observed during the boom are addressed in the following section.

Discussion: Water and Roads

Aside from the ongoing environmental debate, several distinct issues have emerged with respect to unconventional drilling. First, the horizontal drilling and completion methods require substantial amounts of water which can strain local freshwater supplies, especially during periods of drought. Second, the regional drilling and production processes are accompanied by heavy truck traffic which places strain on rural, low-volume county roads. These two prevailing problems are discussed in further detail.

Water Withdrawal and Disposal

Nicot and Scanlon (2012) found that the net water use for unconventional gas extraction represented less than one percent of the statewide water withdrawals. However,

their study also determined that companies drilling in the Barnett Shale consumed approximately nine percent of the water supply in Dallas, Texas. The study projected that by 2024, drilling operations in the Eagle Ford Shale area would consume a similar amount of water as that observed in the Barnett Shale region³⁴. This rapid depletion of local freshwater will pose an impediment for future unconventional booms, especially during periods of drought. Unlike other western states³⁵, Texas groundwater management is based on the common law of capture which bestows the ownership of groundwater to the respective landowners. Therefore, the state has limited control over how much water is pumped out of the aquifers. This is important to consider, particularly, given that groundwater represents 60 percent of the Texas water supplies (Texas Water Plan, 2012).

The majority of proposed water management solutions for unconventional drilling revolve around the topics of water reuse and treatment, reduction, and even replacement. Potential water reuse and treatment options fall under the categories of different physical, chemical, and biological methods. These methods include adsorption of dissolved organics, chemical oxidation, membrane treatment, and electrocoagulation (Ahmadun et al., 2009; Els and Cuba, 2013). The suggested methods may be effective but they are also capital intensive and difficult to implement in the sporadic and agile environment of oil and gas operations. Another potential solution has been the application of propane gels. This water-free approach is nascent and has yet to be applied at a large scale. Some have suggested that areas like South Texas which have ample supplies of propane, may benefit from adopting such a strategy in the future (Galbraith, 2013).

³⁴ Given the current market conditions, this projection is likely to fall short of the estimated amount.

³⁵ In western states like Colorado, Nevada, and New Mexico extraction of groundwater is managed and regulated by the state government.

The aforementioned methods are complex and require further research and technological development. Therefore, simple, regional solutions may ultimately be the optimal choice. For example, a recent study comprehensively analyzed water use in South Texas. In order to address the water availability issues, the authors proposed a collaborative water management approach between the energy industry and the local agricultural sector. Since the agricultural sector consumes the vast majority of regional water, a minor improvement in irrigation efficiencies would lead to substantial water savings. This conserved water can be reallocated for oil and gas exploration. Given the growing costs of purchasing water, this approach may be beneficial for both, farmers and producers (Cook, et al., 2013).

Despite all of the potential water management solutions, the prevailing method for disposing of flowback (produced) water has been the use of underground injection. This method involves injecting wastewater deep into depleted geologic reservoirs through thousands of disposal wells scattered across the state³⁶. Following concerns related to potential earthquakes from high-pressure wastewater injections, the Texas Railroad Commission passed a new rule that requires future injection wells to report supplemental information including past earthquake activity data (Malewitz, 2014b). If the current energy boom subsides as a result of low oil and gas prices, the stress on water supplies will consequently decline as well. However, future energy booms will re-instigate water disputes and the energy industry will likely continue to face water-related encumbrances, especially during periods of limited water supply or drought. Given this likely pressure, potential alternatives should be proactively considered in terms of production costs, efficiency gains, waste reduction, and ultimately water conservation.

³⁶ The brackish water disposal wells are often collocated with oil and gas reservoirs. In fact, these wells are typically drilled into depleted oil and gas fields.

Road Deterioration and Restoration

As briefly discussed in Chapter 5, unconventional drilling operations are accompanied by an inundation of heavy-truck traffic. The entire process of unconventional drilling and completion requires 18-wheelers to haul drill pipe, pumping equipment, water, and produced hydrocarbons. This daily heavy-load traffic places tremendous strain on rural county roads in oil and gas production regions (Miller and Sassin, 2014). The volumetric amount of truck traffic required for a single well has been estimated to be the equivalent of eight million cars (Wilson, 2012). Additionally, Miller and Sassin (2014) note that road damage in the Eagle Ford Shale area may be more extensive than in other production areas. This is primarily because the Barnett Shale and Permian Basin regions exploit previously-installed pipeline networks while the Eagle Ford requires construction of such extensive distribution networks. This presents a dilemma because in the short-term, large pipeline construction projects will further deteriorate the roads. However, in the long-term, pipelines are the preferred method for moving hydrocarbons in lieu of infrastructure-dependent methods like trucks, barges, and trains.

While analysis presented in Chapter 5 indicates increased road spending in some of the impacted counties, it is insufficient to meet the growing demand. Due to funding constraints, in 2013, TxDOT was forced to revert to paving some of the rural roads with gravel instead of pavement (Texas Senate Bill 1747). The deterioration of rural roads is predominantly a state problem as farm-to-market roads are ineligible for federal funding. Recently, the state legislature began taking steps to meet the growing transportation budget shortfalls. In November of 2014, the Texas Transportation Funding Amendment³⁷ passed with an overwhelming majority. This newly approved bill diverts half of the oil and gas

³⁷ Commonly referred to as 'Proposition 1'.

severance taxes from the Economic Stabilization Fund³⁸ to the State Highway Fund. Another important transportation legislation – Texas Senate Bill 5 - was introduced in March of 2015 by the state legislature. The proposed constitutional amendment strives to allocate some of the state vehicle sales tax funds towards the State Highway Fund. Moving from the opposite side of the legislature is Texas House Joint Resolution 13. This proposed measure would allocate funding for transportation from state general sales taxes, instead of from vehicle sales taxes. Regardless of the funding source, both transportation bills are intended to alleviate some of the gaping budget shortfalls.

Much like water management, a proactive plan for future road expenditures would save the impacted communities and the state agencies future budget stress. Research by TxDOT estimated that investing in infrastructure prior to a resource boom would reduce road repair costs by 700 percent compared to a reactive response (Wilson, 2012). Similarly, Tunstall et al. (2014) stressed the importance of long-term planning in regard to sustainability of rural communities. This type of long-term outlook is essential for managing and sustaining the economies of impacted counties. Instead of searching for expensive short-term solutions, stakeholders must assume that future resource booms will inevitably take place and plan accordingly. Partnerships could be formed between the local stakeholders including, county leaders, energy companies, farmers, ranchers, and state agencies. Considering the diverse nature of the Texas economy, there are many stakeholders that must be addressed. For instance, as noted by Wilson (2012), the Texas oil and gas boom coincided with a wind energy boom (Malewitz, 2014c). Consequently, rapid development of wind farms across the state exacerbated the previously mentioned infrastructure problems. The energy boom was also accompanied by a historically severe

³⁸ Commonly known as the ‘Rainy Day Fund’.

drought which impacted farmers, ranchers, and utilities. This spectrum of linked entities allows for distribution of costs across stakeholders and regions. As discussed in the previous section, a partnership between farmers and operators may be a cheaper solution than having to implement expensive water treatment projects that only serve one entity.

Proper management of the financial boom that follows a resource boom is essential in ensuring long term benefits to the impacted communities. Currently, management of an energy boom is a patchwork of short-term solutions overseen by financially strained state agencies. Multilateral partnerships of local and industry stakeholders provide a unique tool for tackling some of the problems discussed in this chapter. The following section reviews the role of policy on both macro and micro scales in regard to the recent energy boom.

Discussion: The Role of Policy in Unconventional Resource Development

On a macro scale, national policies served as the catalyst for unconventional drilling. While the recent energy boom began skyrocketing in the mid-2000s³⁹, the source of the boom can be traced back to the 1970s. In the 1970s, excessive federal regulations artificially placed downward pressure on the price of natural gas and discouraged operators from pursuing natural gas exploration. This resulted in significant gas shortages across the nation, prompting systematic curtailment of gas deliveries to customers (Breyer and MacAvoy, 1973). Appropriately, in 1978 Congress enacted the Natural Gas Policy Act which ultimately sparked deregulation of the U.S. natural gas markets. The deregulation process was further bolstered in 1992 when FERC implemented Order 636, requiring companies to unbundle the sales of natural gas from its transportation (Spence and Prentice, 2012). The removal of artificial price ceilings and encouragement of competition effectively allowed the markets to determine the price of natural gas. This essentially

³⁹ After Mitchell Energy successfully fractured horizontal wells in the Barnett Shale.

formed the backbone of future shale development as operators were allowed to compete in response to fluctuating natural gas prices. In addition to promoting competition, the federal government also funded research and development programs along with tax credits that aimed to promote extraction of unconventional resources. These funding mechanisms helped develop some key technologies including, microseismic fracture mapping (Wang and Krupnick, 2013).

The latest discussion about how national policy impacts oil and gas producers, has revolved around the issue of the U.S. oil export ban (The Economist, 2015). Supporters of the ban praise the artificially low prices, while producers, whose cash margins are negatively affected, deride the discounted prices. From a policy perspective, the restriction of oil exports is a double edged sword. On the one hand, it depresses domestic prices which hurts upstream operators. However, it benefits the downstream operations that are able to process the domestic light sweet crude at a discount as compared to having to purchase Nigerian and Algerian sweet crudes at a premium. Regardless of the political decision on this issue, the current global hydrocarbon market slump will continue to discourage operators from pursuing capital-intensive shale development.

On a micro scale, state and municipal policies can also have a significant impact on the development of unconventional resources. State governments lease state-owned land and set severance tax, lease-terms, and reporting requirements. In Texas, these factors are overseen by multiple state agencies including, the Texas Railroad Commission, the Texas Commission on Environmental Quality, the Texas General Land Office, and the Texas Comptroller of Public Accounts.

In addition to state regulations, resource development can also be directly affected by local municipalities. In November of 2014, the City of Denton passed an ordinance that banned the application of hydraulic fracturing (Malewitz, 2014a) which effectively halted

any future extraction of local natural gas from the Barnett Shale. Promptly following the Denton ordinance, the Texas General Land Office filed a lawsuit seeking an injunction against the ban. The lawsuit argues that the ordinance impairs the Texas General Land Office from exercising its duties of leasing state-owned minerals which directly raise money for the Texas Permanent School Fund (*Jerry Patterson, Commissioner, Texas General Land Office v. City of Denton*). While the Denton ban gained significant media attention, it actually rides on the heels of an earlier ordinance passed by the City of Dallas. In December of 2013, the Dallas City Council passed an ordinance, requiring a minimum 1,500 foot setback for drilling operations near public spaces (Malewitz, 2013). The strict setback is essentially a drilling ban within the city limits.

Such exercises of home rule pit the municipal governments against mineral rights holders and energy companies. The local disputes underscore the complexity of issues that the state legislatures and courts face in respect to unconventional development. On the one hand, resource development brings substantial revenue streams into the state⁴⁰. However, the regulators should also carefully weigh the drawbacks associated with rapid development. It is important that the additional revenues are distributed among counties that are strongly affected by resource development. Poor allocation of funds can cause a backlash among communities that are left stranded with damaged infrastructure and sparse revenues. It is important to remember that these same communities are likely to experience future energy booms. Therefore, partnerships between local, state, and industry groups could be established in order to allocate adequate funding and effectively prepare for future resource development.

⁴⁰ Severance and property (ad-valorem) taxes from mineral extraction are allocated for state and local budgets. Furthermore, collection of state-owned mineral royalties, corporate, and sales taxes from regional economic booms provide additional revenue from resource development.

Chapter 9. Conclusions

The sudden turnaround of the U.S. energy market over the last ten years has been remarkable and Texas stands at the forefront of this phenomenon. As demonstrated in this thesis, the state witnessed significant developments over the past decade. The economies of counties that overlie unconventional formations have been transformed as a result of rapid resource development. However, as illustrated in Chapter 5, the economic boom is accompanied by multiple drawbacks which must be taken into account.

Furthermore, Chapter 7 demonstrated that despite gains in drilling efficiencies and transitions to NGL-rich regions, the longevity of the boom is ultimately dependent on the commodity market trends. Unconventional exploration requires relatively high breakeven prices in order to be sustainable. The recent decline in commodity prices underscores the volatility that is associated with the oil and gas industry. Sharp swings in prices and uncertainty of future market conditions may discourage capital investments in otherwise justifiable upstream and downstream projects. It is important to remember that while oil prices are set globally, due to the difficulty of storing and transporting natural gas, the prices are determined regionally. Therefore the cheap price of American natural gas makes it attractive for exporting. Currently, multiple LNG export terminals are under construction (Kersley et al., 2012). Once operational, these terminals may reduce some of the downward pressure that has been keeping natural gas prices low. Nevertheless, despite the current market slump, future energy booms will likely occur in these regions. Therefore, state and local governments must work closely with industry and regional stakeholders to find proactive solutions that properly manage future booms.

Appendix A

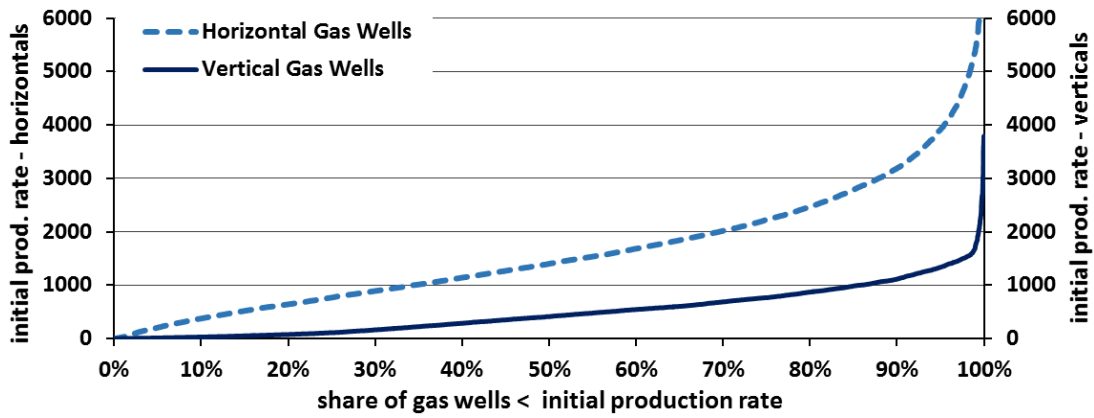


Figure A.1: Initial production rate distributions of horizontal and vertical gas wells in Barnett Shale.

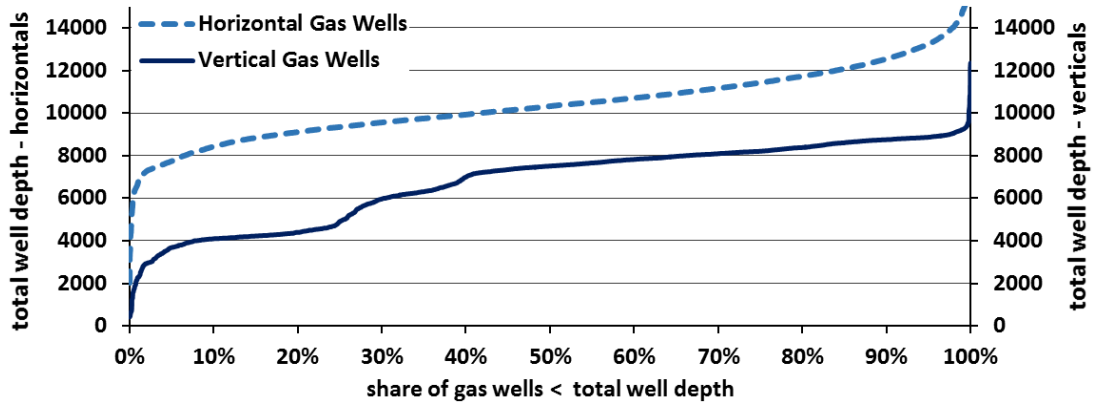


Figure A.2: Depth distributions of horizontal and vertical gas wells in Barnett Shale.

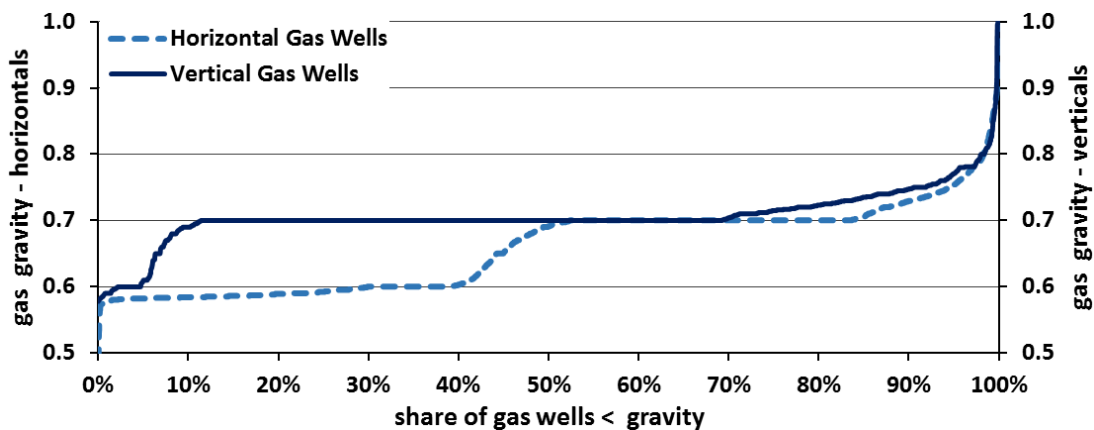


Figure A.3: Gas gravity distributions of horizontal and vertical wells in Barnett Shale.

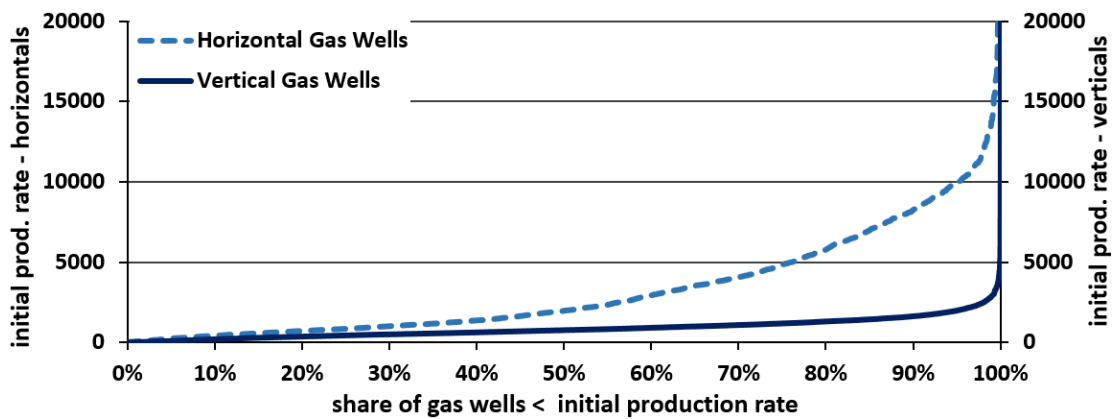


Figure A.4: Initial production rate distributions of horizontal and vertical gas wells in Haynesville Shale.

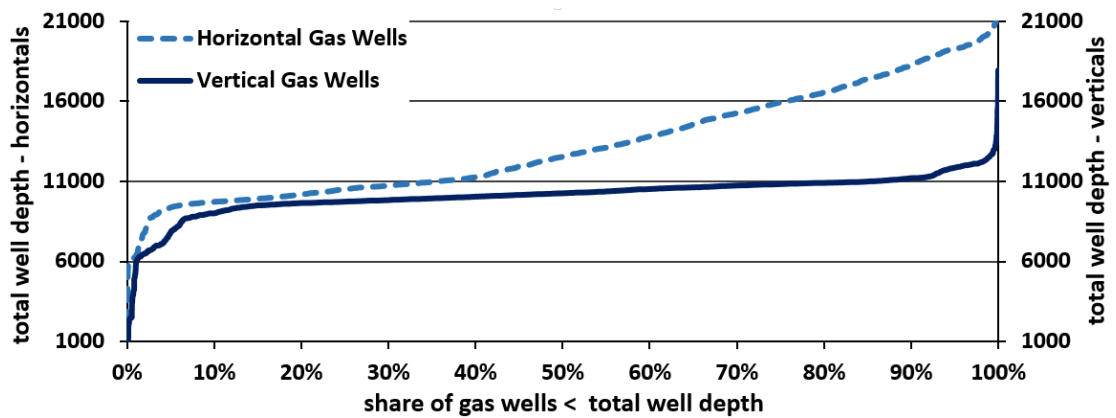


Figure A.5: Depth distributions of horizontal and vertical gas wells in Haynesville Shale.

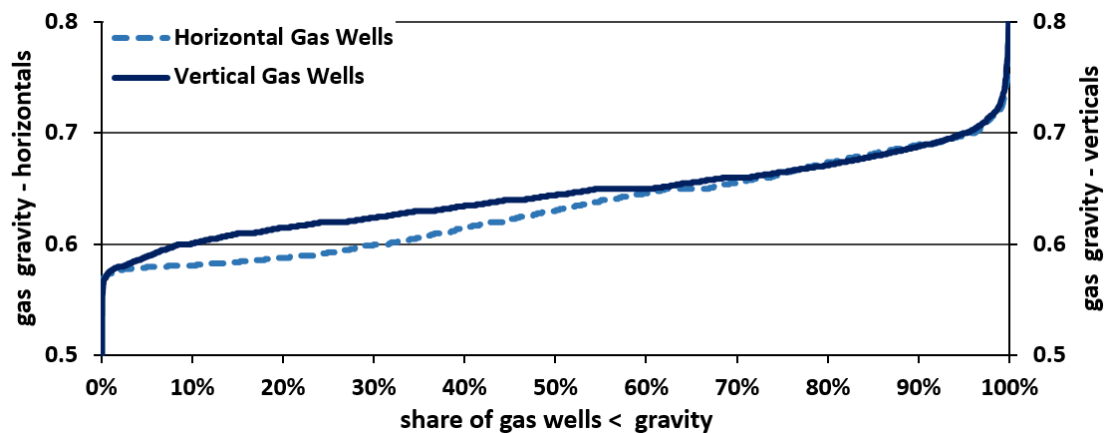


Figure A.6: Gas gravity distributions of horizontal and vertical wells in Haynesville Shale.

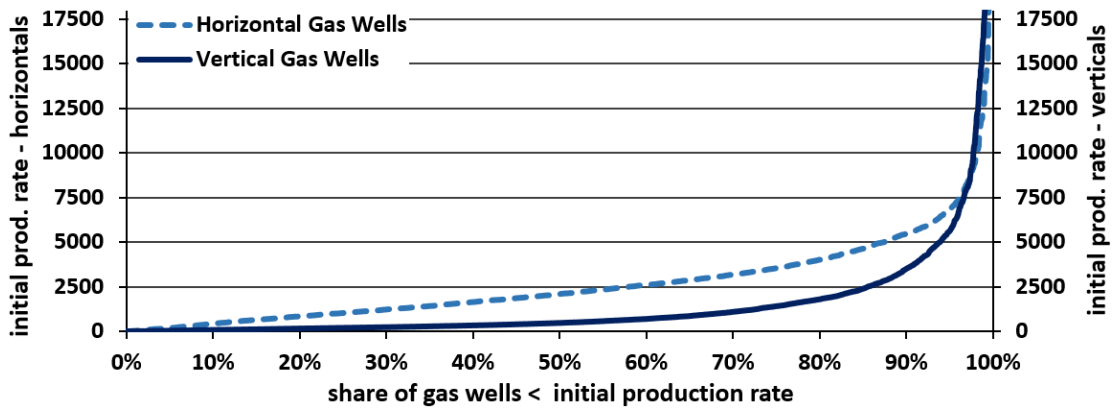


Figure A.7: Initial production rate distributions of horizontal and vertical gas wells in Eagle Ford Shale.

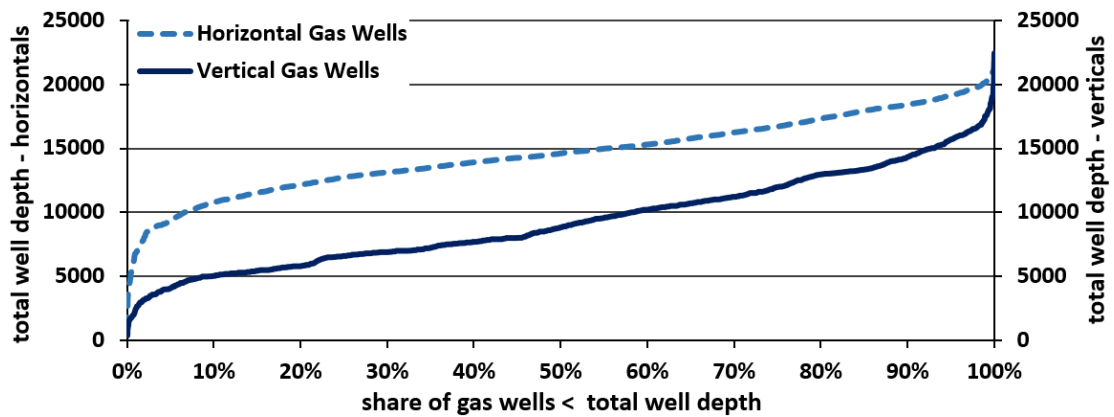


Figure A.8: Depth distributions of horizontal and vertical gas wells in Eagle Ford Shale.

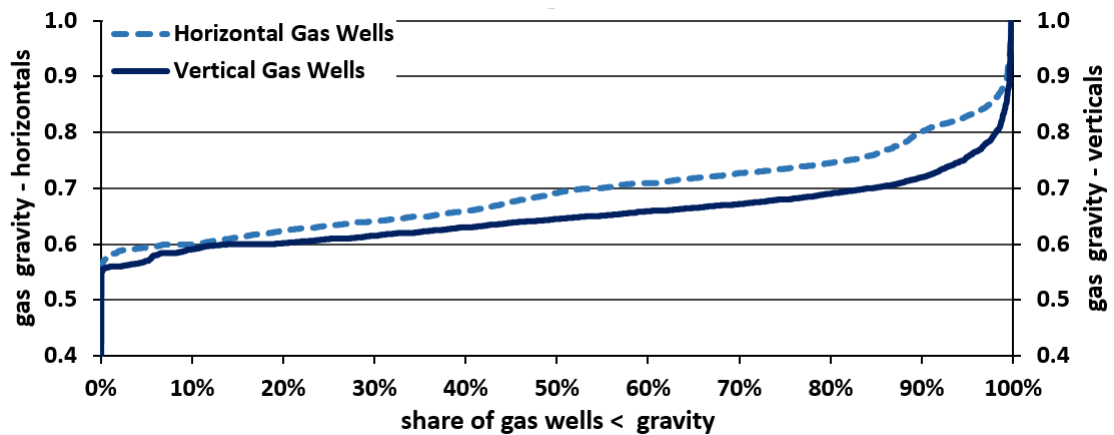


Figure A.9: Gas gravity distributions of horizontal and vertical wells in Eagle Ford Shale.

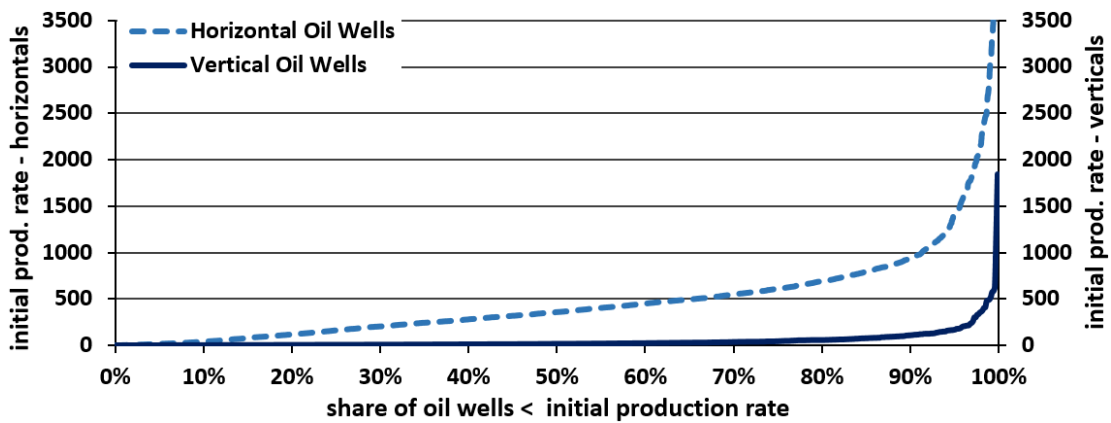


Figure A.10: Initial production rate distributions of horizontal and vertical oil wells in Eagle Ford Shale.

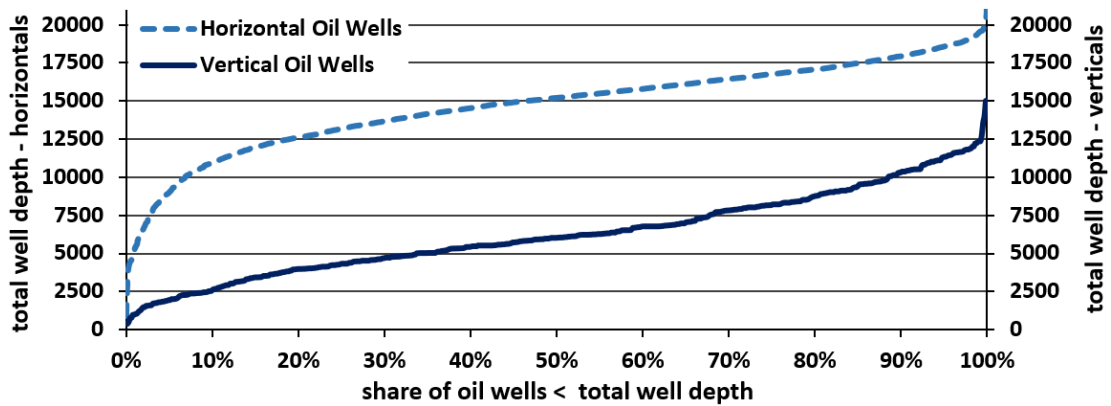


Figure A.11: Depth distributions of horizontal and vertical oil wells in Eagle Ford Shale.

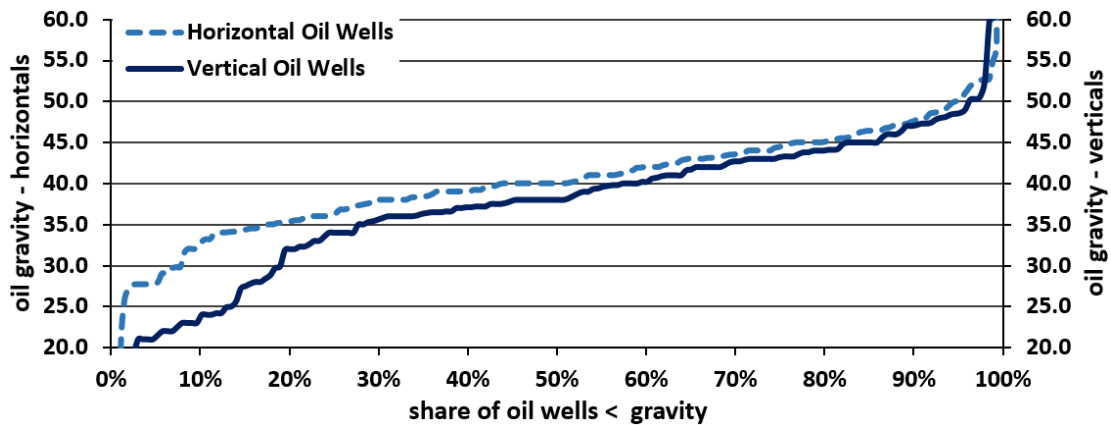


Figure A.12: Oil gravity distributions of horizontal and vertical wells in Eagle Ford Shale.

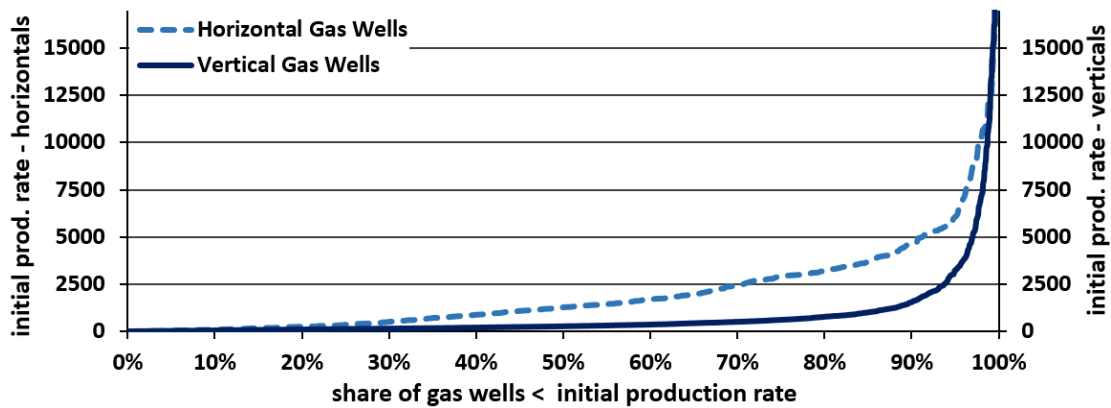


Figure A.13: Initial production rate distributions of horizontal and vertical gas wells in Permian Basin.

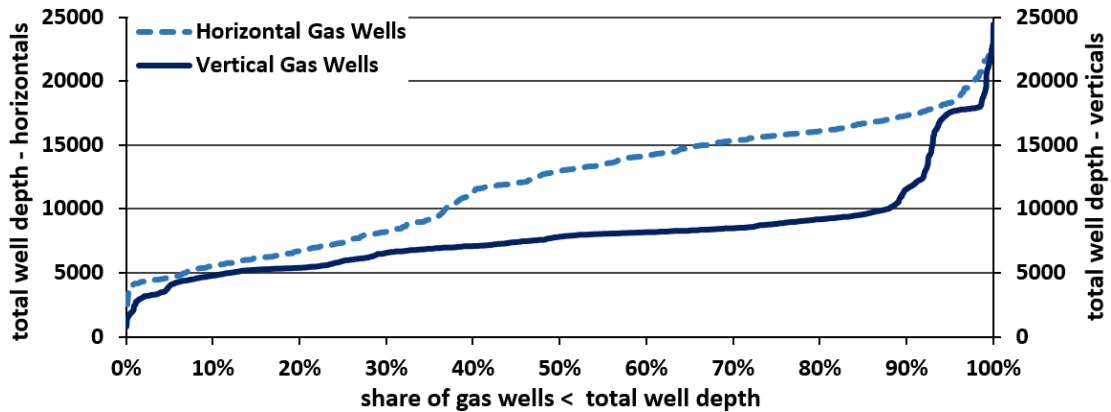


Figure A.14: Depth distributions of horizontal and vertical gas wells in Permian Basin.

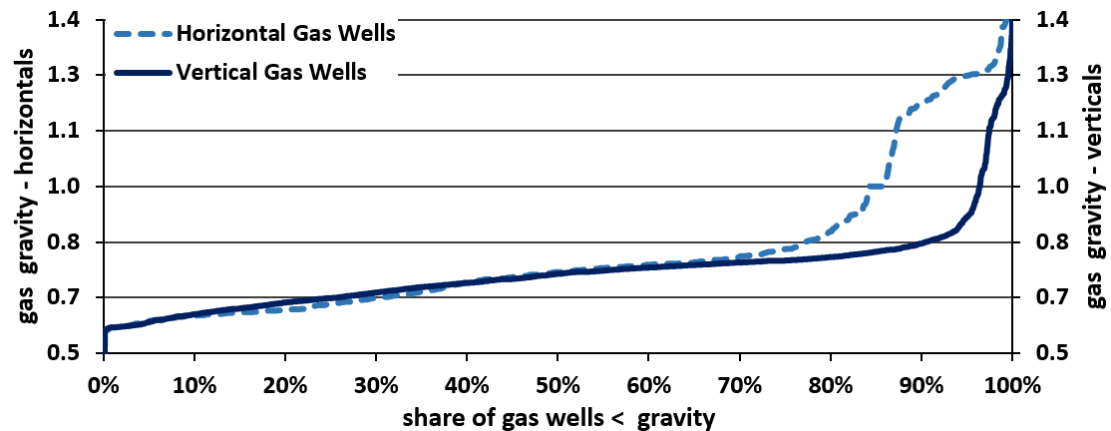


Figure A.15: Gas gravity distributions of horizontal and vertical wells in Permian Basin.

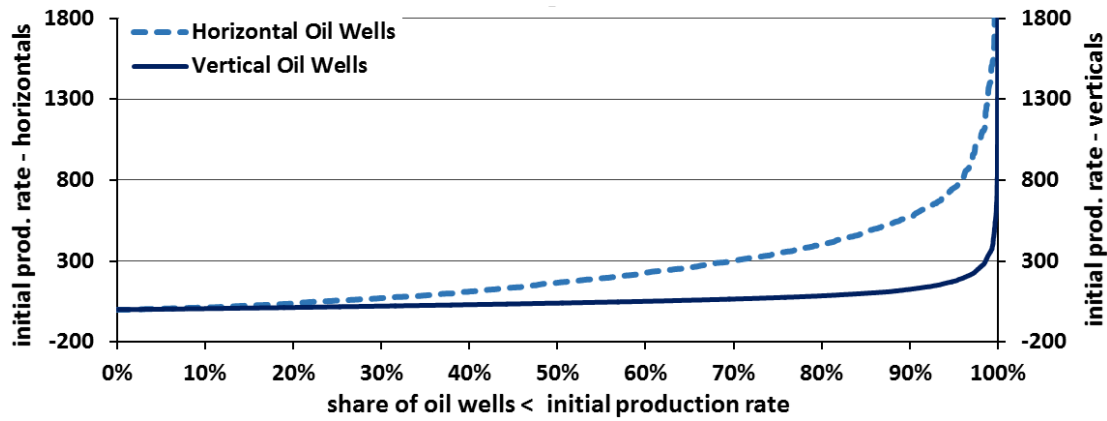


Figure A.16: Initial production rate distributions of horizontal and vertical oil wells in Permian Basin.

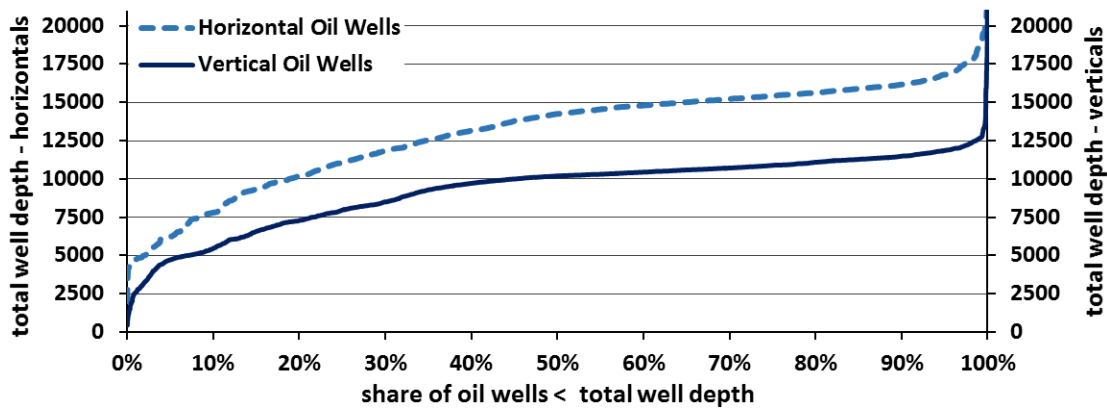


Figure A.17: Depth distributions of horizontal and vertical oil wells in Permian Basin.

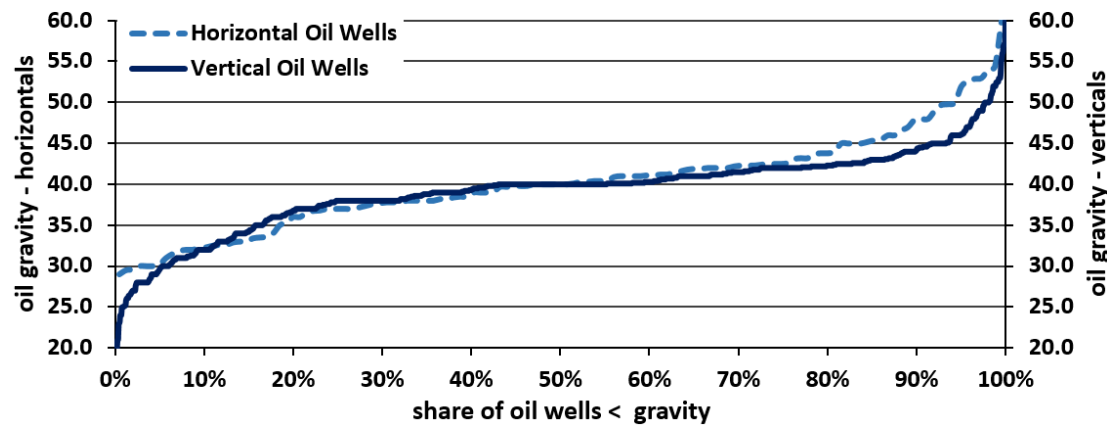


Figure A.18: Oil gravity distributions of horizontal and vertical wells in Permian Basin.

Appendix B

region	well type	drill type	well quality	* q _i	d _i	b - factor	** 15-yr Q (EUR)	** 20-yr Q (EUR)
Eagle Ford	gas	vertical	25th %	2,298	66%	0.8	1,311,830	1,387,579
			50th %	530	69%	1.2	339,673	374,211
			75th %	213	67%	0.9	125,100	133,749
			100th %	63	70%	1.2	38,896	42,818
Eagle Ford	gas	horizontal	25th %	5,568	72%	1.2	3,213,910	3,532,552
			50th %	2,887	68%	1.1	1,823,870	1,991,037
			75th %	1,720	69%	1.3	1,152,723	1,281,791
			100th %	661	67%	1.4	492,668	553,324
Eagle Ford	oil	***vertical	25th %	144	67%	0.9	84,390	90,224
			50th %	26	65%	0.9	16,475	17,646
			75th %	9	66%	1.1	6,178	6,755
			100th %	2	76%	1.2	1,143	1,276
Eagle Ford	oil	horizontal	25th %	1,116	75%	1.1	547,673	594,454
			50th %	453	76%	0.9	191,798	203,436
			75th %	253	75%	0.9	111,394	118,258
			100th %	61	74%	1.4	35,892	40,124
Barnett	gas	*** vertical	25th %	1,122	64%	1.1	804,751	881,398
			50th %	575	65%	1.3	437,576	487,973
			75th %	252	64%	1.2	189,274	209,325
			100th %	44	62%	1.3	36,443	40,730
Barnett	gas	horizontal	25th %	3,657	66%	1.3	2,700,456	3,009,303
			50th %	2,010	63%	1.1	1,485,847	1,628,712
			75th %	1,244	62%	1.5	1,118,327	1,269,981
			100th %	470	62%	1.4	407,090	458,759
Haynesville	gas	vertical	25th %	1,702	73%	1.1	902,156	980,831
			50th %	880	71%	1.3	550,930	611,739
			75th %	537	70%	1.2	332,589	366,126
			100th %	200	69%	1.3	133,796	148,777
Haynesville	gas	*** horizontal	25th %	8,045	73%	1.3	4,681,667	5,190,944
			50th %	3,105	71%	1.1	1,769,997	1,927,505
			75th %	1,253	70%	1.5	879,361	993,647
			100th %	454	69%	1.4	317,359	355,957
Permian	gas	***vertical	25th %	3,037	70%	0.8	1,516,704	1,598,573
			50th %	397	68%	1.2	263,150	290,130
			75th %	172	63%	1.2	133,450	147,703
			100th %	55	61%	1.3	47,076	52,652
Permian	gas	***horizontal	25th %	3,960	63%	1.1	2,927,116	3,208,562
			50th %	1,674	66%	1.2	1,182,721	1,305,992
			75th %	690	65%	1.2	502,783	555,616
			100th %	110	64%	1.1	79,089	86,621
Permian	oil	vertical	25th %	197	67%	1.2	134,926	148,874
			50th %	65	66%	1.3	47,992	53,481
			75th %	35	67%	1.3	25,185	28,045
			100th %	13	67%	1.4	9,540	10,714
Permian	oil	horizontal	25th %	561	75%	1.4	315,206	352,132
			50th %	224	74%	1.3	125,410	138,952
			75th %	96	73%	1.4	58,131	65,028
			100th %	22	71%	1.4	14,038	15,724

region	well type	drill type	well quality	* q_i	d_i	b - factor	** 15-yr Q (EUR)	** 20-yr Q (EUR)
Granite Wash	gas	vertical	25th %	2,498	78%	0.9	971,980	1,029,107
			50th %	1,223	77%	0.9	496,628	526,290
			75th %	752	75%	0.9	331,301	351,715
			100th %	231	61%	1.1	180,804	198,521
Granite Wash	gas	horizontal	25th %	8,008	79%	1.2	3,474,933	3,798,547
			50th %	3,086	74%	1.1	1,574,626	1,710,540
			75th %	1,572	68%	1.3	1,089,345	1,212,185
			100th %	585	64%	1.4	478,271	538,239
Granite Wash	oil	***vertical	25th %	152	80%	0.9	53,979	57,048
			50th %	27	70%	1.1	16,182	17,636
			75th %	10	76%	1.1	4,479	4,857
			100th %	3	81%	1.1	955	1,031
Granite Wash	oil	horizontal	25th %	446	79%	0.8	156,770	163,923
			50th %	165	74%	1.1	83,960	91,207
			75th %	91	73%	1.1	48,195	52,398
			100th %	28	65%	1.3	21,462	23,933

* Gas measured in MCF/D and oil measured in BO/D.

** Gas measured in MCF and oil measured in BO.

*** Due to a limited number of wells (n), a longer time period (outside the 2009-2013 window) was used for the decline curve analysis.

Table B.1: Comprehensive summary of the coefficients applied in the decline curve analysis and the computed EUR values.

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